FORM PTO-1390 (Modified) (REV 11-2000) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTORNEY'S DOCKET NUMBER
TRANSMITTAL LETTER TO THE UNITED STATES · DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371	112740-346
	U.S APPLICATION NO. (IF KNOWN, SEE 37 CFR **10/018312**

INTERNATIONAL APPLICATION NO. **PCT/EP00/01231**	INTERNATIONAL FILING DATE **15 February 2000**	PRIORITY DATE CLAIMED **29 April 1999**

TITLE OF INVENTION

METHOD FOR SYNCHRONIZING A BASE STATION WITH A MOBILE STATION, A BASE STATION AND A MOBILE STATION

APPLICANT(S) FOR DO/EO/US

Juergen Michel et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include itens (5), (6), (9) and (24) indicated below.
4. ☒ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
    - a. ☒ is attached hereto (required only if not communicated by the International Bureau).
    - b. ☐ has been communicated by the International Bureau.
    - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
    - a. ☒ is attached hereto.
    - b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
    - a. ☒ are attached hereto (required only if not communicated by the International Bureau).
    - b. ☐ have been communicated by the International Bureau.
    - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
    - d. ☐ have not been made and will not be made.
8. ☒ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10. ☐ An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).
11. ☒ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☒ A copy of the International Search Report (PCT/ISA/210).

Items 13 to 20 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☒ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
20. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
21. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
22. ☒ Certificate of Mailing by Express Mail
23. ☐ Other items or information:

     PCTUS1/REV03

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR **10/018312**	INTERNATIONAL APPLICATION NO. **PCT/EP00/01231**	ATTORNEY'S DOCKET NUMBER **112740-346**

24.　　　The following fees are submitted:.

CALCULATIONS PTO USE ONLY

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1)–(5)) :

☐ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO $1040.00

☒ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO $890.00

☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO $740.00

☐ International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) $710.00

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CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	15 - 20 =	0	x $18.00	$0.00	
Independent claims	4 - 3 =	1	x $84.00	$84.00	
Multiple Dependent Claims (check if applicable).			☐	$0.00	

TOTAL OF ABOVE CALCULATIONS　=　**$974.00**

☐ Applicant claims small entity status. See 37 CFR 1.27). The fees indicated above are reduced by 1/2.　**$0.00**

SUBTOTAL　=　**$974.00**

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TOTAL NATIONAL FEE　=　**$974.00**

Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **(check if applicable).**　☐　**$0.00**

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NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

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REGISTRATION NUMBER

October 29, 2001
DATE

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IN THE UNITED STATES ELECTED/DESIGNATED OFFICE

OF THE UNITED STATES PATENT AND TRADEMARK OFFICE

UNDER THE PATENT COOPERATION TREATY-CHAPTER II

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PRELIMINARY AMENDMENT

APPLICANTS: Juergen Michel et al.   DOCKET NO.:   112740-346

SERIAL NO: GROUP ART UNIT:

FILED: EXAMINER:

INTERNATIONAL APPLICATION NO::   PCT/EPOO/01231

INTERNATIONAL FILING DATE   15 February 2000

INVENTION: METHOD FOR SYNCHRONIZING A BASE STATION WITH A MOBILE STATION, A BASE STATION AND A MOBILE STATION

Assistant Commissioner for Patents,

10 Washington, D.C. 20231

Sir:

Please amend the above-identified International Application before entry into the National stage before the U.S. Patent and Trademark Office under 35 U.S.C. §371 as follows:

15 **In the Specification:**

Please replace the Specification of the present application, including the Abstract, with the following Substitute Specification:

SPECIFICATION

TITLE OF THE INVENTION

20 METHOD FOR SYNCHRONIZING A BASE STATION WITH

A MOBILE STATION, A BASE STATION AND A MOBILE STATION

BACKGROUND OF THE INVENTION

In signal transmission systems, such as mobile radio systems, it is necessary for one of the communication partners (first transmission unit) to detect specific fixed signals which are

25 emitted by another communication partner (second transmission unit). These can be, for example, what are termed synchronization bursts for synchronizing two synchronization partners such as radio stations, for example, or what are termed access bursts.

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In order to detect or identify such received signals reliably by contrast with the ambient noise, it is known to correlate the received signal continuously with a prescribed signal sequence over a fixed time duration, and to form the correlation sum over the time duration of the prescribed signal sequence. The range of the received signal, which yields a maximum correlation sum, corresponds to the signal being searched for. Connected upstream, as what is termed a training sequence, of the synchronization signal from the base station of a digital mobile radio system is, for example, a signal sequence which is detected or determined in the mobile station in the way just described by correlation with the stored signal sequence. The mobile stations, thus, can be synchronized with the base station.

Such correlation calculations are also necessary in the base station; for example, in the case of random-access-channel (RACH) detection. Moreover, a correlation calculation is also carried out to determine the channel pulse response and the signal propagation times of received signal bursts.

The correlation sum is calculated as follows in this case:

$$Sm = \sum_{i=0}^{n-1} E(i+m) * K(i)$$

E(i) being a received signal sequence derived from the received signal, and K(i) being the prescribed signal sequence, i running from 0 to n-1. The correlation sum Sm is calculated sequentially for a number of temporally offset signal sequences E(i) obtained from the received signal, and then maximum value of Sm is determined. If k sequential correlation sums are to be calculated, the outlay on calculation is k * n operations, the multiplication and addition being counted together as one operation.

The calculation of the correlation sums is, therefore, very complicated and, particularly in real time applications such as voice communication or radio telephony or in CDMA systems, requires powerful and expensive processors which have a high power consumption during calculation. For example, a known signal sequence of length 256 chips (a transmitted bit is also termed a chip in CDMA) is to be determined for the purpose of synchronizing the UMTS mobile radio system, which is being standardized. The sequence is repeated every 2560 chips. Since the mobile station initially operates asynchronously relative to the chip clock, the received signal must be oversampled in order to still retain an adequate

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signal even given an unfavorable sampling situation. Because of the sampling of the I and Q components, this leads to 256*2560*2*2 = 2621440 operations.

WO 96 39749 A discloses transmitting a synchronization sequence, a chip of the sequence itself being a sequence.

5   The use of Golay sequences as an alternative to PN sequences is known from "Srdjan Budisin: Golay Complementary Sequences are Superior to PN Sequences, Proceedings of the International Conference on Systems Engineering, US, New York, IEEE, Vol.-,1992, pages 101-104, XP 000319401 ISBN: 0-7803-0734-8".

It is an object of the present invention to specify methods for synchronizing a base
10   station with a mobile station, as well as to specify a base station and a mobile station, which permits a base station to be synchronized with a mobile station in a way which is reliable and favorable in terms of outlay.

SUMMARY OF THE INVENTION

The present invention is based firstly on the idea of using, for synchronization
15   purposes, signal sequences which can be formed by repeating a second partial signal sequence of length n2 n1 times, in which process the first partial signal sequence (length n1) is used for modulation, and at least one of the partial signal sequences is a Golay sequence; also often termed a Golay complementary sequence. It is, thereby, possible to form signal sequences which can be determined easily when they are contained in a received signal
20   sequence. The use of Golay sequences is advantageous, in particular, because a very effective algorithm is known for this purpose for calculating the correlation.

The present invention is also based on the findings that the use of two partial signal sequences of equal length permits correlation sums to be calculated quickly and favorably in terms of outlay.

25   Thus, for example, given the use of a hierarchical correlation sequence of length 256, which is constructed from 2 constituent Golay sequences of length 16, the computational outlay for the PSC (primary synchronization channel) of a UMTS system can be reduced by contrast with a conventional implementation via a Golay sequence of length 256 from 15 to 14 additions per calculated correlation output value.

30   However, by contrast with an orthogonal gold code used in conventional methods, the autocorrelation function of a signal sequence K(i) formed by two partial signal sequences generally has poorer autocorrelation properties. It has, for example, higher secondary maxima and a higher r.m.s. value of the secondary minima. Moreover, UMTS link level

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simulations show that when such signal sequences K(i) are used in PSC for slot synchronization in the case of a frequency shift (frequency error) between the transmitter and receiver the synchronization error is generally higher than when an orthogonal gold code is used.

5 However, complicated simulation tools created specifically for this aim could be used to determine partial signal sequence pairs (K1(j);K2(k)) consisting of at least one Golay sequence, on the basis of which it is possible to form signal sequences K(i) which can be reliably determined, in particular even given a higher frequency shift between the transmitter and receiver, and thus lead to a small synchronization error. In this case, a frequency shift of 10 10 kHz was also the starting point in the simulations from the UMTS system. The use of a signal sequence K(i) or synchronization code cp that is or can be formed in such a way substantially reduces the outlay on calculating the correlation sums, that is to say for determining the signal sequence K(i) in the receiving mobile station MS for the purpose of synchronization, without the need to accept a simultaneous increase in the synchronization 15 error. Moreover, it is thereby possible to dispense with the use of expensive crystals in the receiver for the purpose of frequency stabilization.

In these simulations, the use of the following Golay sequences as partial signal sequence prove to be particularly advantageous:

A Golay sequence $X_n(k)$ of length nx=16, which can be formed using the following 20 relationship:

$$X_0 \ (k) = \delta \ (k)$$
$$X'_0 \ (k) = \delta \ (k)$$
$$X_n \ (k) = X_{n-1}(k) + W_n \cdot X'_{n-1} \ (k - D_n)$$
$$X'_n \ (k) = X_{n-1}(k) - W_n \cdot X'_{n-1} \ (k - D_n),$$

$$k = 0, \ 1, 2, \ ..., \ 2^{NX} - 1$$
$$n = 1, \ 2, \ ..., \ NX$$
25 $$D_n = 2^{P_n}$$

where

nx=16=2^{NX}

NX=4

$\delta \ (k)$ Kronecker delta function,

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- the permutation P_1, P_2, P_3, P_4 and unit variable W_1, W_2, W_3, W_4 used to form a partial signal sequence being taken from the following set of permutation/unit variable pairs $(P_1, P_2, P_3, P_4, W_1, W_2, W_3, W_4,)$:

3201, +1-1+1+1; 3201, -1-1+1+1; 3201, +1-1-1+1; 3201, -1-1-1+1; 3201, +1-1+1-1; 3201, -1-1+1-1; 3201, +1-1-1-1; 3201, -1-1-1-1; 1023, +1+1-1+1; 1023, -1+1-1+1; 1023, +1-1-1+1; 1023, -1-1-1+1; 1023, +1+1-1-1; 1023, -1+1-1-1; 1023, +1-1-1-1; 1023,-1-1-1-1;.

A specific development of the present invention provides that the permutation P_1, P_2, P_3, P_4 and unit variable W_1, W_2, W_3, W_4 used to form the partial signal sequence is taken from the following set of permutation/unit variable pairs $(P_1 P_2 P_3 P_4, W_1 W_2 W_3 W_4,)$: 3201, +1-1+1+1; 3201, -1-1+1+1; 3201, -1-1+1-1; 3201, +1-1-1-1; and/or the permutation $(P_1 P_2 P_3 P_4)$ used to form the second partial signal sequence is equal to 3201. In addition, a particularly favorable variant implementation of the present invention in ASICs is thereby rendered possible.

Through knowledge concerning the partial signal sequences in the mobile station, it is possible for the calculation of correlation sums that is required to synchronize a mobile station with a base station to be carried out in the mobile station with less outlay compared with the prior art.

In a development of the present invention, partial correlation sums once calculated are stored and used to calculate further correlation sums. It is, thus, possible when calculating further correlation sums to make use of partial correlation sums already calculated and so to reduce the computational outlay enormously.

The term "received signal sequence" also can be understood as a signal sequence which is derived from a received signal by demodulation, filtering, derotation, scaling or analog-to-digital conversion, for example.

Of course, the term "determining a signal sequence" is also understood within the scope of the application as determining the temporal opposition of a signal sequence.

Additional features and advantages of the present invention are described in, and will be apparent from, the following Detailed Description of the Invention and the Figures.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 shows a schematic diagram of a mobile radio network.

Figure 2 shows a block diagram of a radio station.

Figure 3 shows a conventional method for calculating correlation sums.

Figure 4 shows a representation of signal sequences and partial signal sequences according to the teachings of the present invention.

Figure 5 shows a schematic for the formation of the signal sequence according to the teachings of the present invention.

Figures 6, 7 and 8 show a schematic of a method for calculating a correlation sum.

Figures 9 and 10 show a schematic of a variant design of a method for forming the correlation sum.

Figure 11 shows a block diagram of an efficient hierarchical Golay correlator.

DETAILED DESCRIPTION OF THE INVENTION

Illustrated in Figure 1 is a cellular mobile radio network such as, for example, the GSM (Global System for Mobile Communication), which includes a multiplicity of mobile switching centers MSC which are networked with one another and/or provide access to a fixed network PSTN/ISDN. Furthermore, these mobile switching centers MSC are connected to, in each case, at least one base station controller BSC, which can also be formed by a data processing system. A similar architecture is also to be found in a UMTS (Universal Mobile Telecommunication System).

Each base station controller BSC is connected, in turn, to at least one base station BS. Such a base station BS is a radio station which can use an air interface to set up a radio link to other radio stations, what are termed mobile stations MS. Information inside radio channels f which are situated inside frequency bands b can be transmitted via radio signals between the mobile stations MS and the base station BS assigned to these mobile stations MS. The range of the radio signals of a base station substantially defines a radio cell FZ.

Base stations BS and a base station controller BSC can be combined to form a base station system BSS. The base station system BSS is also responsible in this case for radio channel management and/or assignment, data rate matching, monitoring the radiotransmission link, hand-over procedures and, in the case of a CDMA system, assigning the spread code set to be used, and transfers the signaling information required for this purpose to the mobile stations MS.

For FDD (Frequency-Division Duplex) systems such as the GSM, it is possible in the case of a duplex system to provide for the uplink u (mobile station (transmitting unit) to the base station (receiving unit)) frequency bands differing from those for the downlink d (base station (transmitting unit) to the mobile station (receiving unit)). A number of frequency

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channels f can be implemented within the different frequency bands b via an FDMA (Frequency-Division Multiple Access) method.

Within the scope of the present application, the transmission unit is also understood as a communication unit, transmitting unit, receiving unit, communication terminal, radio station, mobile station or base station. Terms and examples used within the scope of this application frequently refer also to a GSM mobile radio system; however, they are not in any way limited thereto, but can easily be mapped by a person skilled in the art with the aid of the description onto other, possibly future, mobile radio systems such as CDMA systems; in particular, wide-band CDMA systems. Data can be efficiently transmitted, separated and assigned to one or more specific connections and/or to the appropriate subscriber via an air interface via multiple access methods. It is possible to make use for this purpose of time-division multiple access TDMA, frequency-division multiple access FDMA, code-division multiple access CDMA or a combination of a number of these multiple access methods.

In FDMA, the frequency band b is broken down into a number of frequency channels f; these frequency channels are split up into time slots ts via time division multiple access TDMA. The signals transmitted within a time slot ts and a frequency channel f can be separated via spread codes, what is termed CDMA codes cc, that are modulated in a link-specific fashion onto the data.

The physical channels thus produced are assigned to logic channels according to a fixed scheme. The logic channels are physically distinguished into two types: signaling channels (or control channels) for transmitting signaling information (or control information) and, traffic channels (TCH) for transmitting useful data.

The signaling channels are further subdivided into:
- broadcast channels
- common channels
- dedicated/access control channels DCCH/ACCH

The group of broadcast channels includes the broadcast control channel BCCH, to which the MS receives radio information from the base station system BSS, the frequency correction channel FCCH and the synchronization channel SCH. The common control channels include the random access channel RACH. The bursts or signal sequences that are transmitted to implement these logic channels can include in this case for different purposes signal sequences K(i), what are termed correlation sequences, or signal sequences K(i) can be

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transmitted on these logic channels for different purposes. A method for synchronizing a mobile station MS with a base station BS is explained below by way of example. During a first step of the initial search for a base station or search for a cell (initial cell search procedure), the mobile station uses the primary synchronization channel (SCH (PSC)) in

5   order to achieve a time slot synchronization with the strongest base station. This can be ensured via a matched filter or an appropriate circuit which is matched to the primary synchronization code cp that is emitted by all the base stations. In this case, all the base stations BS emit the same primary synchronization code cp of length 256.

The mobile station uses correlation to determine from a received sequence the

10   received signal sequences K(i), using a principle which is explained in Figures 6 to 11 and the associated description. In this case, peaks are output by the output of a matched filter for each received signal sequence of each base station located within the reception area of the mobile station. The detection of the position of the strongest peak permits the determination of the timing of the strongest base station modulo of the slot length. In order to ensure a

15   greater reliability, the output of the matched filter can be accumulated over the number of time slots in the non-coherent fashion. The mobile station therefore carries out a correlation over a signal sequence of length 256 chips as a matched-filter operation.

The synchronization code cp is formed in this case in accordance with a signal sequence K(i) using a principle as explained in Figure 5 and the associated description, or can

20   be formed in such a way or can be obtained in such a way. The signal sequence K(i) or the synchronization code cp of length 256 is formed in this case from two partial signal sequences K1(j), K2(k), of length 16 in each case, or can be formed in such a way. These partial signal sequences form a partial signal sequence pair (K1(j); K2(k)) in this case.

A signal sequence K(i) obtainable in such a way can also be termed in this case a

25   "hierarchical signal sequence" or "hierarchical correlation sequence". A partial signal sequence can also be termed a "short correlation sequence" or "constituent sequence".

In this case, at least one partial signal sequence is a Golay sequence, also termed a Golay complementary sequence of length nx, denoted *here by $X = X_{NX}(k)$*. X can be formed using the following relationship:

$$X_0 (k) = \delta (k)$$
$$X'_0 (k) = \delta (k)$$
$$X_n (k) = X_{n-1}(k) + W_n \cdot X'_{n-1} (k - D_n)$$
$$X'_n (k) = X_{n-1}(k) - W_n \cdot X'_{n-1} (k - D_n),$$

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$$k = 0, 1, 2, ..., 2^{NX}-1$$
$$n = 1, 2, ..., NX$$
$$D_n = 2^{P_n}$$

5   where

$$nx = 2^{NX}$$

δ *(k)* Kronecker delta function

P_n, n = 1, 2, ...*NX;* arbitrary permutation of the numbers {0, 1, 2, ..., *NX*-1},

W_n weights for the partial signal sequence (+1,-1,+i or -i).

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A method of Golay and Sivaswamy for generating Golay sequences as such is also
known from "Efficient Pulse compressor for Golay Complementary Sequences", Electronic
Letters Vol. 27, No. 3, pp. 219.

W_n can, therefore, assume the values +1, -1, +i or -i, or, in particular, assume the
15   values +1 or -1 for the purpose of generating binary Golay sequences.

Within the scope of the present application, W_n is also denoted as a unit variable. The
set of the variables D_n, used for a Golay sequence, which can be calculated from the
permutation P_n, is also denoted as delay matrix; the set of the selected weights W_n is also
denoted as a weight matrix.

20   For example, W = [1,-1,1,1] can be selected for the unit variable and/or the weights of
the weight matrix, which means that $W_1 = 1$; $W_2 = -1$; $W_3 = 1$; $W_4 = 1$ and for the delay
matrix D = [8,4,1,2], which means that $D_1=8=2^3=2^{P1}$; $D_2=4=2^2=2^{P2}$; $D_3=1=2^0=2^{P3}$;
$D_4=2=2^1=2^{P4}$. The permutation or permutation matrix P=[3;2;0;1] yields the partial signal
sequence X_4 = (1 1 1 -1 -1 1 -1 -1 1 1 1 -1 1 -1 1 1). This sequence can be used as one of the
25   partial signal sequences such as K1(j), for example.

By contrast with an orthogonal gold code used in conventional methods, the
autocorrelation function of a signal sequence K(i) formed by two partial signal sequences
generally has poorer autocorrelation properties. It has, for example, higher secondary
maxima and a higher r.m.s. value of the secondary minima. Moreover, UMTS link level
30   simulations show that when such signal sequences K(i) are used in PSC for slot
synchronization in the case of a frequency shift (frequency error) between the transmitter and
receiver the synchronization error is generally higher by contrast with the use of an
orthogonal gold code.

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However, complicated simulation tools created specifically for this aim could be used to determine partial signal sequence pairs (K1(j);K2(k)) consisting of at least one Golay sequence, on the basis of which it is possible to form signal sequences K(i) which can be reliably determined, in particular, for synchronization between the base station and mobile station even in the case of a relatively high frequency shift between the transmitter and receiver, and thus lead to a small synchronization error. In this case, a frequency shift of 10 kHz was also the starting point in the simulations for the UMTS system. The use of a signal sequence K(i) or synchronization code cp that is or can be formed in such a way substantially reduces the outlay on calculating the correlation sums, that is to say on determining the signal sequence K(i) in the receiving mobile station MS for the purpose of synchronization, without the need to accept a simultaneous increase in the synchronization error. Moreover, it is also possible to dispense with the use of expensive crystals in the receiver for the purpose of frequency stabilization.

The calculation of the autocorrelation function as a function of the frequency error proved to be particularly suitable in the case of the simulations for the purpose of assessing the synchronization properties of a signal sequence K(i) formed by a permutation-unit variable pair.

The calculation of the autocorrelation function taking account of a frequency shift between the transmitting and receiving units can also be carried out in this case in accordance with the following formula:

$$a(\kappa) = ABS\left(\sum_{i=0}^{n-1-\kappa} K(i) \bullet [K(i+\kappa) \bullet \exp(j \bullet 2\pi \bullet f_d \bullet i \bullet t_a))]^*\right.$$

κ shift

n   length of the sequence

i   index

f_d frequency shift

t_a sampling interval

[]*   denotes the complex conjugate

In this case, the values $a(\kappa)$ can be calculated for $\kappa=0..n-1$. If the result is a number of partial signal sequence pairs which lead to an equally good ratio of principal maximum to the maximum secondary maximum in the autocorrelation function of the resulting signal sequence $K(i)$, the partial signal sequence pairs which lead to a lower r.m.s. value of the secondary maxima can be selected in what follows. In this case, the ratio of the principal maximum to the maximum secondary maximum is to be as large as possible, and the r.m.s. value of the secondary minima is to be as small as possible. By using subsequent link level simulations on the UMTS system, for example, it is possible to determine partial signal sequence pairs which in the case of frequency errors of 0 kHz and 5 KHz and 10 kHz surprisingly behave with regard to the synchronization error as effectively as a conventional orthogonal gold code, which is not hierarchically designed and is known to have very good properties for synchronization.

In addition to the autocorrelation function, the following criteria can also be used to select partial signal sequence pairs $(K1(j);K2(k))$:

-        Missed detection rate: select the partial signal sequence pairs by comparing the missed detection rate when carrying out complete simulations.

-        Detection probabilities for a given frequency error and a given SNR in the case of AWGN channels.

It was possible using the complicated simulations to determine a set of Golay sequences of length 16, described by a set of permutation/unit variable pairs which is specified in one and/or more of claims 1, 2, 3 or 4 on the basis of which it is possible to form signal sequences $K(i)$ which have a small synchronization error both for a frequency shift of zero between the transmitter and receiver and for a larger frequency shift in the case of use for synchronization purposes. This leads to a preferred selection of permutation/unit variable pairs from which

partial signal sequences and, finally, signal sequences $K(i)$ can be obtained or formed.

In one variant design of the present invention, at least one partial signal sequence is a Golay sequence in particular of length 16, optimized with regard to the secondary maxima of the autocorrelation function even in the case of frequency errors.

It turned out to be advantageous, in the case of the simulations explained above, to use a signal sequence $K(i)$ based on a partial signal sequence, the permutation P_1, P_2, P_3, P_4 and complex unit variable W_1, W_2, W_3, W_4 used to form the partial signal sequence being

taken from the following set of permutation/unit variable pairs (P_1, P_2, P_3, P_4, W_1, W_2, W_3, W_4;):

0213,+j+j+j-1; 0213,-j+j+j-1; 0213,+1-j+j-1; 0213,-1-j+j-1;

0213,+1+j-j-1; 0213,-1+j-j-1; 0213,+j-j-j-1; 0213,-j-j-j-1;

0213,+j+j+j+1; 0213,-j+j+j+1; 0213,+1-j+j+1; 0213,-1-j+j+1;

0213,+1+j-j+1; 0213,-1+j-j+1; 0213,+1-j-j+1; 0213,-j-j-j+1;

3120,+1-j+j-1; 3120,-1-j+j-1; 3120,+1+j-j-1; 3120,-1+j-j-1;

3120,+1+j+j+j; 3120,-1-j+j+j; 3120,+1-j-j+j; 3120,-1-j-j+j;

3120,+1+j+j-j; 3120,-1+j+j-j; 3120,+1-j-j-j; 3120,-1-j-j-j;

3120,+1-j+j+1; 3120,-1-j+j+1; 3120,+1+j-j+1; 3120,-1+j-j+1;

It proved to be particularly advantageous in the case of the simulations explained above to use a signal sequence $K(i)$ based on a partial signal sequence, the permutation P_1, P_2, P_3, P_4 and binary unit variable W_1, W_2, W_3, W_4 used to form the partial signal sequence being taken from the following set of permutation/unit variable pairs (P_1, P_2, P_3, P_4, W_1, W_2, W_3, W_4):

3201, +1-1+1+1; 3201, -1-1+1+1; 3201, +1-1-1+1; 3201, -1-1-1+1; 3201, +1-1+1-1; 3201, -1-1+1-1; 3201, +1-1-1-1; 3201, -1-1-1-1; 1023, +1+1-1+1; 1023, -1+1-1+1; 1023, +1-1-1+1; 1023, -1-1-1+1; 1023, +1+1-1-1; 1023, -1+1-1-1; 1023, +1-1-1-1; 1023, -1-1-1-1;.

It proved to be particularly advantageous in the case of the simulations explained above to use a signal sequence $K(i)$ based on a partial signal sequence, the permutation P_1, P_2, P_3, P_4 and binary unit variable W_1, W_2, W_3, W_4 used to form the partial signal sequence being taken from the following set of permutation/unit variable pairs (P_1, P_2, P_3, P_4, W_1, W_2, W_3, W_4):

3201, +1-1+1+1; 3201, -1-1-1+1; 3201, -1-1+1-1; 3201, +1-1-1-1; and the permutation (P_1, P_2, P_3, P_4) used to form the second partial signal sequence is equal to 3201.

As already explained above, in addition to the permutation/unit variable representation, it is also possible to represent the Golay sequences by specifying the delay matrix and the weight matrix. The sequence with real weights which is specified as particularly advantageous in the first place above, the sequence (3201,+1-1+1+1) specified by the parameters (P_1, P_2, P_3, P_4, W_1, W_2, W_3, W_4) is therefore defined by the delay matrix $D = [8, 4, 1, 2]$ and the weight matrix $W = [1, -1, 1, 1]$.

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Furthermore, the Golay sequence can also be represented explicitly by specifying the individual elements, the result for the above-named Golay sequence of length 16 being in this case:

$$K1= <+1,+1,+1,-1,-1,+1,-1,-1,+1,+1,+1,-1,+1,-1,+1,+1>$$

5   A further equivalent representation follows in the case of the mapping from +1 to 0 and -1 to 1 that is frequently used in the literature. The sequence is then defined by:

$$<0,0,0,1,1,0,1,1,0,0,0,1,0,1,0,0>$$

Thus, if Golay sequences of length 16 are used as partial signal sequences (constituent sequences) for the PSC of UMTS, $W_n=1,-1, i -i$ being permitted as weights, an arbitrary

10   permutation from $D_n=\{1,2,4,8\}$ being permitted as delays, the result is more than 2_{12} different possibilities for each of the two constituent sequences, that is to say a total of 2_{24} possibilities. In accordance with certain embodiments, the present invention includes approximately 10 to $10^{\wedge}2$ permutation/unit variable pairs. The selected permutation/unit variable pairs therefore form only a very small subset of the fundamentally possible set of permutation/unit variable

15   pairs that can be used to form 16-digit Golay sequences.

Figure 2 shows a radio station which can be a mobile station MS, consisting of an operating unit or interface unit MI, a control device STE, a processing device VE, a power supply device SVE, a receiving device EE and, if appropriate, a transmitting device SE.

The control device STE essentially includes a program-controlled microcontroller

20   MC, which can access memory chips SPE by writing and reading. The microcontroller MC controls and monitors all essential elements and functions of the radio station.

The processing device VE can also be formed by a digital signal processor DSP, which can, likewise, access memory chips SPE. Addition and multiplication can be effected via the processing device VE.

25   The program data required for controlling the radio station and the communication cycle, as well as, in particular, the signaling procedures, and information produced during the processing of signals are stored in the volatile or nonvolatile memory chips SPE. Moreover, signal sequences K(i) which are used for correlation purposes, and intermediate results of correlation sum calculations can also be stored therein. The signal sequences K(i) within the

30   scope of the present invention can be stored in the mobile station and/or the base station. It is also possible for one or more of the permutation/unit variable pairs set forth above or partial signal sequences or partial signal sequence pairs (K1(j);K2(k)) derived therefrom to be stored in the mobile station and/or the base station. It is also possible for a signal sequence K(i) to

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be formed from a partial signal sequence pair (K1(j);K2(k)) and/or a partial signal sequence to be formed from a permutation/unit variable pairs in the mobile station and/or the base station.

In particular, it is possible to store in a base station, or in all the base stations in a system, a signal sequence K(i) which is emitted at fixed or variable intervals for synchronization purposes. The partial signal sequence pair (K1(j);K2(k)), from which the signal sequence K(i) stored in the base station can be formed, is stored in the mobile station MS and is used to synchronize the mobile station with a base station in order to calculate the correlation sum favorably in terms of computation outlay.

The storage of the signal sequences or the partial signal sequences can also be performed by storing appropriate information in arbitrarily coded form, and can be implemented with the aid of storage parts such as, for example, volatile and/or nonvolatile memory chips or via appropriately designed adder or multiplier inputs or appropriate hardware configurations which have the same effect.

The high-frequency section HF includes, if appropriate, the transmitting device SE, with a modulator and an amplifier V, and a receiving device EE with a demodulator and, likewise, an amplifier. The analog audio signals and the analog signals originating from the receiving device EE are converted via analog-to-digital conversion into digital signals and processed by the digital signal processor DSP. After processing, the digital signals are converted, if appropriate, by digital-to-analog conversion into analog audio signals or other output signals and analog signals that are to be fed to the transmitting device SE. Modulation or demodulation, respectively, is carried out for this purpose, if appropriate.

The transmitting device SE and the receiving device EE are fed with the frequency of a voltage-controlled oscillator VCO via the synthesizer SYN. The system clock for timing processor devices of the radio station can also be generated via the voltage-controlled oscillator VCO.

An antenna device ANT is provided for receiving and for transmitting signals via the air interface of a mobile radio system. The signals are received and transmitted in what are termed bursts that are pulsed over time in the case of some known mobile radio systems such as the GSM (Global System for Mobile Communication).

The radio station may also be a base station BS. In this case, the loudspeaker element and the microphone element of the operating unit MMI are replaced by a link to a mobile radio network; for example, via a base station controller BSC or a switching device MSC.

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The base station BS has an appropriate multiplicity of transmitting and receiving devices, respectively, in order to exchange data simultaneously with a number of mobile stations MS.

The received signal sequence E(l), which can also be a signal sequence derived from a received signal, of length w is illustrated in Figure 3. In order to calculate a first correlation sum S0 in accordance with the formula specified at the beginning, elements of a first section of this received signal sequence E(l) are multiplied in pairs by the corresponding elements of the signal sequence K(i) of length n, and the length of the resulting partial results is added to the correlation sum S0.

In order to calculate a further correlation sum S1, as illustrated in the Figure 3, the signal sequence K(i) is shifted to the right by one element, and the elements of the signal sequence K(i) are multiplied in pairs by the corresponding elements of the signal sequence E(l), and the correlation sum S1 is formed again by summing the partial results produced.

The pairwise multiplication of the elements of the signal sequence by corresponding elements of the received signal sequence, and the subsequent summation can also be described in vector notation as the formation of a scalar product, if the elements of the signal sequence and the elements of the received signal sequence are respectively aligned to form a vector of a Cartesian coordinate system:

$$S0 = \begin{pmatrix} K(0) \\ \vdots \\ K(i) \\ \vdots \\ K(n-1) \end{pmatrix} * \begin{pmatrix} E(0) \\ \vdots \\ E(i) \\ \vdots \\ E(n-1) \end{pmatrix} = K(0)*E(0)+...+K(i)*E(i)+...+K(n-1)*E(n-1)$$

$$S1 = \begin{pmatrix} K(0) \\ \vdots \\ K(i) \\ \vdots \\ K(n-1) \end{pmatrix} * \begin{pmatrix} E(1) \\ \vdots \\ E(i+1) \\ \vdots \\ E(n) \end{pmatrix} = K(0)*E(1)+...+K(i)*E(i+1)+...+K(n-1)*E(n)$$

In the correlation sums S thus determined, it is possible to search for the maximum and compare the maximum of the correlation sums S with a prescribed threshold value and thus determine whether the prescribed signal sequence K(i) is included in the received signal E(l) and if so where it is located in the received signal E(l) and thus two radio stations are

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synchronized with one another or data are detected on to which an individual spread code has been modulated in the form of a signal sequence K(i).

Represented again in Figure 4 is the received signal sequence E(l) and, as correlation sequence a signal sequence K(i) which is based on the partial signal sequences K1(j), K2(k).

5   Represented in Figure 5 is the formation of a signal sequence K(i) which is based on two partial signal sequences K2(k) of length n2 and K1(j) of length n1. For this purpose, the partial signal sequence K2(k) is repeated n1 times and modulated in the process by the partial signal sequence K1(k). The formation of the signal sequence K(i) can also be expressed mathematically by the following formula:

10    $K(i) = K2(i \bmod n2) * K1(i \, \mathrm{div} \, n2)$, for $i = 0 \ldots n1*n2-1$

mod denotes the integral remainder of a division, and div denotes the integral result of a division.

This is illustrated by a sequence f2 which consists of the repeated, sequentially mapped partial signal sequences K2(k), and a sequence f1 which is mapped by an extended

15   partial signal sequence K1(j) over the sequence f2.

The new signal sequence K(i) of length n is produced by multiplying the elements of the sequence f2 by the corresponding elements, mapped over the sequence f2, of the sequence f1. This generation of a signal sequence K(i) is represented once again at the bottom of the illustration with the aid of an example of two binary partial signal sequences of length 4.

20   The present invention is not, of course, limited to partial signal sequences of length 4 or signal sequences of length 16. Neither is the present invention limited to the mathematical description used above.

For example, the following representation for partial signal sequences of length 16 or signal sequences of length 256 correspond in content to the mathematical representation used

25   above, and is likewise contained in the present invention:

For example, if use is made for K1 of the Golay sequence, described above as particularly favorable, with the permutation/unit variable representation (3201 , +1-1+1+1) or the explicit representation <+1,+1,+1,-1,-1,+1,-1,-1,+1,+1,+1,-1,+1-1,+1,+1>, and for K2 of a sequence a consisting of 16 elements, it is also possible to write the repeated, sequentially

30   mapped partial signal sequences K2 and a, which are modulated with the value of the respective element of the sequence K1, as follows:

$K = <a, a, a, -a, -a, a, -a, -a, a, a, a, -a, a, -a, a, a>$

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Signal sequences K(i) formed in such a way can be used for simplified calculation of correlation sums of these signal sequences K(i) with received signal sequences E(l). The signal sequence of length 256 thus formed can, for example, be emitted for synchronization purposes as primary synchronization code cp of length 256.

5   A schematic of such a simplified calculation of correlation sums S which is, therefore, also faster and more favorable in terms of outlay, is represented in Figures 6 to 8, which are examined below.

The first step is to form a partial correlation sum TS(z). For this purpose, for example, the correlation sum of the second partial signal sequence K2(k) with the

10   corresponding section of the received signal sequence E(l) is formed for the first element of the partial correlation sequence TS(0).

$$TS(0) = \begin{pmatrix} K2(0) \\ \cdot \\ K2(k) \\ \cdot \\ K2(n2-1) \end{pmatrix} * \begin{pmatrix} E(0) \\ \cdot \\ E(k) \\ \vdots \\ E(n2-1) \end{pmatrix} = K2(0) * E(0) + ... + K2(k) * E(k) + ... + K2(n2-1) * E(n2-1)$$

15   As illustrated, for the second element of the partial correlation sum sequence TS(1) the second partial signal sequence K2(k) is shifted by one element, and the correlation sum with the corresponding element of the received signal sequence E(l) is likewise formed, etc.

$$TS(1) = \begin{pmatrix} K2(0) \\ \cdot \\ K2(k) \\ \cdot \\ K2(n2-1) \end{pmatrix} * \begin{pmatrix} E(1) \\ E(k+1) \\ \vdots \\ E(n2) \end{pmatrix} = K2(0) * E(1) + . + K2(k) * E(k+1) + ... + K2(n2-1) * E(n2)$$

20

The n-th element of the partial correlation sum sequence TS(n1*n2-1) is calculated correspondingly after n-1 shifts of the second partial signal sequence K2(k) with respect to the received signal sequence E(l).

$$TS(n-1) = \begin{pmatrix} K2(0) \\ \vdots \\ K2(k) \\ \vdots \\ K2(n2-1) \end{pmatrix} * \begin{pmatrix} E(n-1) \\ \vdots \\ E(k+n-1) \\ \vdots \\ E(n2+n-2) \end{pmatrix} =$$

$$= K2(0) * E(n-1) + ... + K2(k) * E(k+n-1) + ... + K2(n2-1) * E(n2+n-2)$$

The partial correlation sum sequence TS(z) thus produced is represented at the top in Figure 7. Each n2-th element is now selected from this partial correlation sum sequence and multiplied by the corresponding element of the first partial signal sequence K1(j) in pairs.

Combining the selected elements of the partial correlation sum sequence TS(z) and the first partial signal sequence K1(k) to form vectors in each case produces the first correlation sum S0 via the scalar product of these two vectors.

$$S0 = \begin{pmatrix} K1(0) \\ \vdots \\ K1(j) \\ \vdots \\ K1(n1-1) \end{pmatrix} * \begin{pmatrix} TS(0) \\ \vdots \\ TS(j*n2-1) \\ \vdots \\ TS((n1-1)*n2-1) \end{pmatrix} = K1(0) * TS(0) + ... + K1(j) * TS(j*n2-1) + ...$$

Figure 7 shows at the bottom the corresponding calculation of further correlation sums S1 and S2, respectively, through the selection of n2-th elements situated one or two to the right of the initially selected elements:

$$S1 = \begin{pmatrix} K1(0) \\ \vdots \\ K1(j) \\ \vdots \\ K1(n1-1) \end{pmatrix} * \begin{pmatrix} TS(1) \\ \vdots \\ TS(j*n2) \\ \vdots \\ TS((n1-1)*n2) \end{pmatrix} = K1(0) * TS(0) + ... + K1(j) * TS(j*n2) + ...$$

By storing partial correlation sums TS once calculated, it is possible to have recourse to them again when later calculating further correlation sums, and thus to dispense with the corresponding computational steps.

Depending on the design variant, it is possible either firstly to calculate the complete partial correlation sum sequence TS(z) over the entire received signal sequence E(l), and then to calculate the individual correlation sums, or not to calculate the corresponding additionally

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required partial correlation sums until required for the purpose of calculating a new correlation sum.

Figure 8 shows, once again, the method consisting of two steps, for calculating correlation sums S, this time with the aid of the example, represented in Figure 5, of two binary partial signal sequences of length 4.

In a first step, the partial correlation sums $TS(z)$ of the second partial signal sequence $K2(k)$ +-++ are calculated with corresponding sections of the received signal sequence $E(l)$ and, in a second step, each fourth element of the partial correlation sum sequence $TS(z)$ thus produced is then selected, multiplied by the corresponding element of the first partial signal sequence $K1(j)$ +++-, and summed to form the correlation sequence $S0$.

The bold lines in this case represent the calculation steps that have to be carried out anew for calculation of a further correlation sum $S1$ for the case in which the remaining partial correlation sums TS have already previously been calculated and stored.

This variant design can be carried out as efficiently as possible in terms of storage if each n2-th partial correlation sum is firstly calculated. The samples are buffered for this purpose.

Figures 9 to 10 present another variant design for simplified calculation of correlation sums S with the aid of the example, already mentioned above, of two binary partial signal sequences of length 4.

The first step here is to select each 4th element of the received signal sequence $E(l)$ and to form the partial correlation sum sequence $TS(z)$ of the elements thus selected with the partial signal sequence $K1(k)$. Four sequential elements are respectively selected from the partial correlation sum sequence $TS(z)$ thus produced and multiplied in pairs by corresponding elements of the partial signal sequence $K2(k)$, and the resulting partial results are summed to form the correlation sum S. Once again, here, the bold lines represent the additionally required steps for calculating a further correlation sum $S1$ for the case in which the other partial correlation sums TS have already been calculated and stored before.

Figure 10 shows, once again, the calculation of a first correlation sum $S0$, in the case of which, firstly, each 4th element of the received signal sequence $E(l)$ is selected, these elements are multiplied by corresponding elements of the first partial signal sequence $K1(k)$ +++-, and the partial correlation sum $TS(0)$ is calculated by summing the partial results. In a second step, the first 4 sequential elements of the partial correlation sum sequence $TS(z)$ are multiplied by the corresponding elements of the second partial signal

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sequence K2(k) +-++, and the partial results produced are summed to form the correlation sum S0.

This variant design requires less storage for buffering the partial correlation sums when the sums are calculated successively.

5   A further refinement of the present invention utilizes the regular (fast periodic) structure, caused by the regular design principle of the signal sequence K(i), of the aperiodic autocorrelation function of this signal sequence. As such, when a signal is being sought, not only is a principal maximum produced, but secondary maxima also occur at regular intervals. The regularity of the position of the maxima can be utilized to accelerate the search for the

10   signal sequence in the received signal sequence. As soon as a secondary maxima has been found, it is possible to predict the position of the other maxima on the basis of the periodicity. That is to say the correlation sum is calculated only at these points. The principal maximum can be detected quickly in this way. However, the supposed secondary maximum can also be only a randomly increased value (because of the noise component). In this case, no

15   maximum will actually be found at the potential points of the expected principal maximum. Consequently, the hypothesis is rejected in this case and the calculation is continued conventionally.

However, the regularity, caused by the design principle of the signal sequences, of the secondary maxima can also be utilized to eliminate and correct interfering secondary maxima

20   in the correlation result. After the detection of the maximum, the secondary maxima can be calculated therefrom and this value can be subtracted from the corresponding correlation results. The correlation result of a (hypothetical) sequence with a perfect autocorrelation function is obtained in this way. This results in a greatly simplified calculation owing to the regularity of the secondary maxima.

25   In various embodiments of the present invention, efficient Golay correlators are used to calculate scalar products, correlation sums and/or partial correlation sums.

Figure 11 shows an efficient hierarchical correlator for signal sequences, Golay sequences X,Y of length nx and ny respectively being used as constituent sequences K1, K2. The correlator consists of two series-connected matched filters (Figure 11a) which are

30   respectively formed as efficient Golay correlators. Figure 11b shows the matched filter for the sequence X, and Figure 11 c shows the matched filter for the sequence Y.

The following designations apply in Figure 11 b:

$n = 1, 2, ...NX$

20

ny   length of sequence Y

nx   length of sequence X

NX   with $nx=2^{NX}$

DX_n $DX_n = 2^{PX_n}$

PX_n permutation of the numbers {0, 1, 2, ..., *NX*-1}

for the partial signal sequence X

WX_n weights for the partial signal sequence X

from (+1,-1,+i or -i).

The following designations apply in Figure 11 c:

n = 1, 2, ...NY

ny   length of sequence Y

NY   with $ny=2^{NY}$

DY_n $DY_n = 2^{PY_n}$

PY_n permutation of the numbers {0, 1, 2, ..., *NY*-1} for the partial

signal sequence Y

WY_n weights for the partial signal sequence Y from (+1,-1,+i or -i)

Moreover, the following definitions and designations are valid in these variant designs:

$a_n(k)$ and $b_n(k)$ are two complex sequences of length 2^N,

$\delta(k)$ is the Kronecker delta function

k is an integer representing time,

n is the iteration number,

D_n is the delay,

P_n, $n = 1, 2, ..., N$, is an arbitrary permutation of the numbers

{0, 1, 2, ..., *N*-1},

W_n can assume the values +1, -1, +i, -i as weights and is also designated as unit variable.

The correlation of a Golay sequence of length 2^N can now be carried out efficiently as follows:

The sequences $R_a(0)(k)$ and $R_b(0)(k)$ are defined as $R_a(0)(k) = R_b(0)(k) = r(k)$, r(k) being the received signal or the output of another correlation stage.

The following step is executed N times: n runs from 1 to N:

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Calculate

$$R_a^{(n)}(k) = W^*_n * R_b^{(n-1)}(k) + R_a^{(n-1)}(k - D_n)$$

and

$$R_b^{(n)}(k) = W^*_n * R_b^{(n-1)}(k) + R_a^{(n-1)}(k - D_n),$$

5   W^*_n designating the complex conjugate of W_n. If the weights W are real, W^*_n is identical to W_n.

$R_a^{(n)}(k)$ is then the correlation sum to be calculated.

An efficient Golay correlator for a PSC code of length 256 (2^8) chips in the receiver generally has $2 \cdot 8 - 1 = 15$ complex adders. With the combination of hierarchical correlation

10   and efficient Golay correlator, a hierarchical code, described by two constituent sequences X and Y, of length 256 ($2^4 \cdot 2^4$) requires only $2 \cdot 4 - 1 + 2 \cdot 4 - 1 = 14$ complex adders (even when use is made of four-valued constituent sequences). This reduces by 7% the outlay on calculation, which is very high for the primary synchronization in CDMA mobile radio systems.

Specified below, marked in each case by dividing dashes, of variant designs of the

15   present invention the implementation of which are within the activity of a person skilled in the art given knowledge of the present application:

-      to form a code sequence of length 2^{NX+NY}, two constituent Golay sequences of length $nx = 2^{NX}$ and $ny = 2^{NY}$ are used and are hierarchically constructed as described above.

20   -   +1 and -1 are used as weights for the constituent Golay sequences, binary sequences thereby being produced.

-      +1, -1, i or -i are used as weights for the constituent Golay sequences, four-valued sequences thereby being produced.

-      Real Golay sequences are used.

25   -   Complex Golay sequences are used.

-      Two constituent Golay sequences of equal length are used.

-      Two complementary Golay sequences are used.

-      Only one efficient Golay correlator, with programmable delays, if appropriate, is used for optional calculation of one or both complementary Golay sequences.

30   -   A sequence is used as described, but additional values are also inserted; these values must be accumulated as usual during the calculation. The remainder of

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the calculation can, however, be carried out efficiently as described. This permits the generation of sequences of arbitrary length.

- Two constituent sub-sequences are used.

- A number of constituent sub-sequences are used.

- A Golay sequence is used only for some of the sub-sequences.

- These sequences are used for the synchronization channel in UMTS.

- Constituent Golay sequences optimized for frequency error are used.

- Two series-connected filters are used to calculate the correlation, one being a matched filter matched to the Golay sequence X, the other being a matched filter matched to the Golay sequence Y with spread delays $ny \cdot DX_n$.

- Two series-connected filters are used to calculate the correlation, one being a matched filter matched to the Golay sequence X, and the other being a matched filter matched to the Golay sequence Y with spread delays $ny \cdot DX_n$, and the output signals of the filters being calculated in accordance with the efficient Golay correlator algorithm.

- The efficient Golay correlation algorithm is used to calculate the partial correlation sums and the algorithm for the hierarchical correlation is used to determine the overall correlation.

The present invention is not limited to radio transmission systems, but can also be employed in the use of other transmission methods, for example, acoustic method (ultrasound) in particular, for the purposes of sonography, or optical methods, for example infrared measurement using lidar principles. A further field of application is the investigation of changes in the spectral composition of backscattered signals.

Indeed, although the present invention has been described with reference to specific embodiments, those of skill in the art will recognize that changes made be made thereto without departing from the spirit and scope of the invention as set forth in the hereafter appended claims.

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ABSTRACT OF THE DISCLOSURE

Method for forming and determining a signal sequence, a synchronization method, a transmitting unit and a receiving unit , including the formation of signal sequences which are based on partial signal sequences, the second partial signal sequence being repeated and modulated in the process by the first partial signal sequence, and at least one of the signal sequences being a Golay sequence, and use of these partial signal sequences for the purpose of simplified calculation of correlation sums in a two-stage calculation method, one partial correlation sum sequence being calculated first.

In the claims:

On page 32, cancel line 1 and substitute the following left hand justified heading therefore:

CLAIMS

Please cancel claims 1-15, without prejudice, and substitute the following claims therefore:

16.   A method for synchronizing a base station with a mobile station, the method comprising the steps of:

forming a signal sequence K(i) of length 256, to be emitted by the base station, in accordance with the following relationship wherein a second partial signal sequence K2(k) of length n2=16 is repeated n1=16 times and is modulated in the process with a first partial signal sequence K1(j) of length n1=16, modulation of the second partial signal sequence K2(k) being performed using the following rule:

K(i) = K2(i mod n2) * K1(i div n2), for i =0 ...n1*n2-1;

forming at least one of the partial signal sequences, being a Golay sequence $X_n(k)$ of length nx=n1=16, using the following relationship:

$$X_0 (k) = \delta (k)$$
$$X'_0 (k) = \delta (k)$$
$$X_n (k) = X_{n-1}(k) + W_n \cdot X'_{n-1} (k - D_n)$$
$$X'_n (k) = X_{n-1}(k) - W_n \cdot X'_{n-1} (k - D_n),$$

$$k = 0, 1, 2, ..., 2^{NX-1}$$

$$n = 1, 2, ..., NX$$

$$D_n = 2^{P_n}$$

where

$$nx = 16 = 2^{NX}$$

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NX=4

δ (k): Kronecker delta function; and

taking the permutation P_1, P_2, P_3, P_4 and unit variable W_1, W_2, W_3, W_4 used to form a partial signal sequence from the following set of permutation/unit variable pairs $(P_1, P_2, P_3, P_4, W_1, W_2, W_3, W_4;)$:

3201, +1-1+1+1; 3201, -1-1+1+1; 3201, +1-1-1+1; 3201, -1-1-1+1; 3201, +1-1+1-1; 3201, -1-1+1-1; 3201, +1-1-1-1; 3201, -1-1-1-1; 1023, +1+1-1+1; 1023, -1+1-1+1; 1023, +1-1-1+1; 1023, -1-1-1+1; 1023, +1+1-1-1; 1023, -1+1-1-1; 1023, +1-1-1-1; 1023, -1-1-1-1;.

17.   A method for synchronizing a base station with a mobile station as claimed in claim 16, wherein the signal sequence K(i) is formed using the following formation law by modulated repetition of a partial signal sequence a consisting of 16 elements:

$K = <a, a, a, -a, -a, a, -a, -a, a, a, a, -a, a, -a, a, a>$

18.   A method for synchronizing a base station with a mobile stations as claimed in claim 16, wherein the partial signal sequence K1(j) is a Golay sequence which is defined by the delay matrix D = [8,4,1,2] and the weight matrix W = [1,-1, 1,1].

19.   A method for synchronizing a base station with a mobile station as claimed in claim 16, wherein the permutation P_1, P_2, P_3, P_4 and unit variable W_1, W_2, W_3, W_4 used to form the first partial signal sequence is taken from the following set of permutation/unit variable pairs $(P_1, P_2, P_3, P_4, W_1, W_2, W_3, W_4)$:

3201, +1-1+1+1; 3201, -1-1-1+1; 3201, -1-1+1-1; 3201, +1-1-1-1; and

the permutation P_1, P_2, P_3, P_4 used to form the second partial signal sequence is equal to 3201.

20.   A method for synchronizing a base station with a mobile station as claimed in claim 16, wherein the signal sequence K(i) is received by the mobile station as part of a received signal sequence and further processed for synchronization purposes.

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21. A method for synchronizing a base station with a mobile station as claimed in claim 16, wherein the signal sequence K(i) is determined by the mobile station, knowledge of the first and second partial signal sequences K1(j) K2(k) being used in the mobile station.

22. A method for synchronizing a base station with a mobile station as claimed in claim 16, the method further comprising the steps of:

determining correlation sums of the signal sequence K(i) with corresponding sections of the received signal sequence in the mobile station;

calculating a partial correlation sum sequence of the partial signal sequence K2(k) with corresponding parts of the received signal sequence; and

selecting n1 elements of the partial correlation sum sequence to calculate a correlation sum and multiplying the n1 elements by the partial signal sequence K1(j) to produce a scalar product.

23. A method for synchronizing a base station with a mobile station as claimed in claim 22, wherein n1 in each case n2-th elements of the partial correlation sum sequence are selected to calculate a correlation sum.

24. A method for synchronizing a base station with a mobile station as claimed in claim 16, the method further comprising the steps of:

determining correlation sums of the signal sequence K(i) with corresponding sections of the received signal sequence in the mobile station;

calculating a partial correlation sum sequence of the partial signal sequence K2(k) with corresponding elements of the received signal sequence; and

multiplying n2 elements of the partial correlation sum sequence by the partial signal sequence K2(k) to produce a scalar product in order to calculate a correlation sum.

25. A method for synchronizing a base station with a mobile station as claimed in claim 24, wherein n1 in each case n2-th elements of the received signal sequence E(l) are selected to calculate a partial correlation sum.

26

26.   A method for synchronizing a base station with a mobile station as claimed in claim 22, wherein calculated partial correlation sums are stored and used to calculate a further correlation sum.

27.   A method for synchronizing a base station with a mobile station as claimed in claim 16, wherein an efficient Golay correlator is used in the mobile station in order to determine, at least partially, the signal sequence and to calculate at least one correlation sum.

28.   A method for synchronizing a base station with a mobile station, the method comprising the steps of:

forming a synchronization sequence K of length 256 to be emitted by the base station, as follows from a partial signal sequence a consisting of 16 elements:

K = <a, a, a, -a, -a, a, -a, -a, a, a, a, -a, a, -a, a, a>; and

receiving the synchronization sequence K, at the mobile station, and processing it for synchronization purposes.

29.   A base station comprising:

a part for storing or forming a signal sequence K(i) in accordance with the following relationship wherein a partial second signal sequence K2(k) of length n2=16 is repeated n1=16 times and is modulated in the process by the first partial signal sequence K1(j) of length n1=16, the modulation of the second partial signal sequence K2(k) being performed using the following rule:

k(i) = K2(i mod n2) * K1(i div n2), for i =0 ...n1*n2-1,

at least one of the partial signal sequences being a Golay sequence $X_n(k)$ of length nx=n1=16 which can be formed using the following relationship

$$X_0\ (k) = \delta\ (k)$$
$$X'_0\ (k) = \delta\ (k)$$
$$X_n\ (k) = X_{n-1}(k) + W_n \cdot X'_{n-1}\ (k - D_n)$$
$$X'_n\ (k) = X_{n-1}(k) - W_n \cdot X'_{n-1}\ (k - D_n),$$

$$k = 0, 1, 2, ..., 2^{NX}-1$$
$$n = 1, 2, ..., NX$$
$$D_n = 2^{P_n}$$

27

where

$$nx=16=2^{NX}$$

$$NX=4$$

$\delta(k)$: Kronecker delta function,

the permutation P_1, P_2, P_3, P_4 and unit variable W_1, W_2, W_3, W_4 used to form the partial signal sequence being taken from the following set of permutation/unit variable pairs ($P_1 P_2 P_3 P_4, W_1 W_2 W_3 W_4$;):

3201, +1-1+1+1; 3201, -1-1+1+1; 3201, +1-1-1+1; 3201, -1-1-1+1; 3201, +1-1+1-1; 3201, -1-1+1-1; 3201, +1-1-1-1; 3201, -1-1-1-1; 1023, +1+1-1+1; 1023, -1+1-1+1; 1023, +1-1-1+1; 1023, -1-1-1+1; 1023, +1+1-1-1; 1023, -1+1-1-1; 1023, +1-1-1-1; 1023, -1-1-1-1; and

parts for emitting the signal sequence K(i) with the aim of synchronization with a receiving unit.

30.   A mobile station comprising a part for determining a signal sequence K(i), in accordance with the following relationship wherein a second partial signal sequence K2(k) of length n2=16 is repeated n1=16 times and is modulated in the process with a first partial signal sequence K1(j) of length n1=16, the modulation of the second partial signal sequence K2(k) being performed using the following rule:

K(i) = K2(i mod n2) * K1(i div n2), for i =0 ...n1*n2-1,

at least one of the partial signal sequences being a Golay sequence $X_n(k)$ of length nx=n1=16, which can be formed using the following relationship:

$$X_0(k) = \delta(k)$$
$$X'_0(k) = \delta(k)$$
$$X_n(k) = X_{n-1}(k) + W_n \cdot X'_{n-1}(k - D_n)$$
$$X'_n(k) = X_{n-1}(k) - W_n \cdot X'_{n-1}(k - D_n),$$

$$k = 0, 1, 2, ..., 2^{NX}-1$$
$$n = 1, 2, ..., NX$$
$$D_n = 2^{P_n}$$

where

$$nx=16=2^{NX}$$

$$NX=4$$

$\delta(k)$: Kronecker delta function,

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the permutation P_1, P_2, P_3, P_4 and unit variable W_1, W_2, W_3, W_4 used to form a partial

signal sequence being taken from the following set of permutation/unit variable pairs ($P_1 P_2$

$P_3 P_4, W_1 W_2 W_3 W_4$;):

3201, +1-1+1+1; 3201, -1-1+1+1; 3201, +1-1-1+1; 3201, -1-1-1+1; 3201, +1-1+1-1; 3201, -1-1+1-1; 3201, +1-1-1-1; 3201, -1-1-1-1; 1023, +1+1-1+1; 1023, -1+1-1+1; 1023, +1-1-1+1; 1023, -1-1-1+1; 1023, +1+1-1-1; 1023, -1+1-1-1; 1023, +1-1-1-1; 1023, -1-1-1-1;

and knowledge of the first and second partial signal sequences K1(j) K2(k) being

used.

R E M A R K S

The present amendment makes editorial changes and corrects typographical errors in

the specification, which includes the Abstract, in order to conform the specification to the

requirements of United States Patent Practice. No new matter is added thereby. Attached

hereto is a marked-up version of the changes made to the specification by the present

amendment. The attached page is captioned "**Version With Markings To Show Changes**

Made".

In addition, the present amendment cancels original claims 1-15 in favor of new

claims 16-30. Claims 16-30 have been presented solely because the revisions by crossing out

underlining which would have been necessary in claims 1-15 in order to present those claims

in accordance with preferred United States Patent Practice would have been too extensive,

and thus would have been too burdensome. The present amendment is intended for

clarification purposes only and not for substantial reasons related to patentability pursuant to

35 U.S.C. §§103, 102, 103 or 112. Indeed, the cancellation of claims 1-15 does not constitute

an intent on the part of the Applicants to surrender any of the subject matter of claims 1-15.

Early consideration on the merits is respectfully requested.

Respectfully submitted,

_____ (Reg. No. 39,056)

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In The Specification:

The Specification of the present application, including the Abstract, has been amended as follows:

5
SPECIFICATION

TITLE OF THE INVENTION

<u>METHOD FOR SYNCHRONIZING A BASE STATION WITH</u>

<u>A MOBILE STATION, A BASE STATION AND A MOBILE STATION</u>

~~Description~~

10 ~~Method for synchronizing a base station with a mobile station, a base station and a mobile station~~

BACKGROUND OF THE INVENTION

~~The invention relates to a method for synchronizing a base station with a mobile station, a base station and a mobile station.~~

15 In signal transmission systems, such as mobile radio systems, it is necessary for one of the communication partners (first transmission unit) to detect specific fixed signals which are emitted by another communication partner (second transmission unit). These can be, for example, what are termed synchronization bursts for synchronizing two synchronization partners such as radio stations, for example, or what are termed access bursts.

20 In order to detect or identify such received signals reliably by contrast with the ambient noise, it is known to correlate the received signal continuously with a prescribed signal sequence over a fixed time duration, and to form the correlation sum over the time duration of the prescribed signal sequence. The range of the received signal, which yields a maximum correlation sum, corresponds to the signal being searched for. Connected

25 upstream, as what is termed a training sequence, of the synchronization signal from the base station of a digital mobile radio system, is, for example, a signal sequence which is detected or determined in the mobile station in the way just described by correlation with the stored signal sequence. The mobile stations can, thus, be synchronized with the base station.

Such correlation calculations are also necessary in the base station, for example, in

30 the case of random-access-channel (RACH) detection. Moreover, a correlation calculation is also carried out to determine the channel pulse response and the signal propagation times of received signal bursts.

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The correlation sum is calculated as follows in this case:

$$Sm = \sum_{i=0}^{n-1} E(i+m) * K(i)$$

5   E(i) being a received signal sequence derived from the received signal, and K(i) being the

prescribed signal sequence, i running from 0 to n-1. The correlation sum Sm is calculated

sequentially for a ~~plurality~~ number of temporally offset signal sequences E(i) obtained from

the received signal, and then maximum value of Sm is determined. If k sequential correlation

sums are to be calculated, the outlay on calculation is k * n operations, the multiplication and

10   addition being counted together as one operation.

The calculation of the correlation sums is, therefore, very complicated and,

particularly in real time applications such as voice communication or radio telephony or in

CDMA systems, requires powerful, and ~~therefore~~ expensive processors which have a high

power consumption during calculation. For example, a known signal sequence of length

15   256 chips (a transmitted bit is also termed a chip in CDMA) is to be determined for the

purpose of synchronizing the UMTS mobile radio system, which is being standardized. The

sequence is repeated every 2560 chips. Since the mobile station initially operates

asynchronously relative to the chip clock, the received signal must be oversampled in order to

~~still~~ retain an adequate signal even given an unfavorable sampling situation. Because of the

20   sampling of the I and Q components, this leads to 256*2560*2*2 = 2621440 operations.

WO 96 39749 A discloses transmitting a synchronization sequence, a chip of the

sequence itself being a sequence.

The use of Golay sequences as an alternative to PN sequences is known from "Srdjan

Budisin: Golay Complementary Sequences are Superior to PN Sequences, Proceedings of the

25   International Conference on Systems Engineering, US, New York, IEEE, Vol.-,1992, pages

101-104, XP 000319401 ISBN: 0-7803-0734-8".

It is ~~the~~ an object of the present invention to specify methods for synchronizing a base

station with a mobile station, as well as to specify a base station and a mobile station, which

permits a base station to be synchronized with a mobile station in a way which is reliable and

30   favorable in terms of outlay.

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SUMMARY OF THE INVENTION

The present invention is based firstly on the idea of using, for synchronization

5 purposes, signal sequences which can be formed by repeating a second partial signal sequence of length n2 n1 times, in which process the first partial signal sequence (length n1) is used for modulation, and at least one of the partial signal sequences is a Golay sequence, also often termed a Golay complementary sequence. It is, thereby, possible to form signal sequences which can be determined easily when they are contained in a received signal

10 sequence. The use of Golay sequences is advantageous, in particular, because a very effective algorithm is known for this purpose for calculating the correlation.

The present invention is also based on the findings that the use of two partial signal sequences of equal length permits correlation sums to be calculated quickly and favorably in terms of outlay.

15 Thus, for example, given the use of a hierarchical correlation sequence of length 256, which is constructed from 2 constituent Golay sequences of length 16, the computational outlay for the PSC (primary synchronization channel) of a UMTS system can be reduced by contrast with a conventional implementation ~~by means of~~ via a Golay sequence of length 256 from 15 to 14 additions per calculated correlation output value.

20 However, by contrast with an orthogonal gold code used in conventional methods, the autocorrelation function of a signal sequence K(i) formed by two partial signal sequences generally has poorer autocorrelation properties. It has, for example, higher secondary maxima and a higher r.m.s. value of the secondary minima. Moreover, UMTS link level simulations show that when such signal sequences K(i) are used in PSC for slot

25 synchronization in the case of a frequency shift (frequency error) between the transmitter and receiver the synchronization error is generally higher than when an orthogonal gold code is used.

However, complicated simulation tools created specifically for this aim could be used to determine partial signal sequence pairs (K1(j);K2(k)) consisting of at least one Golay

30 sequence, on the basis of which it is possible to form signal sequences K(i) which can be reliably determined, in particular even given a higher frequency shift between the transmitter and receiver, and thus lead to a small synchronization error. In this case, a frequency shift of 10 kHz was also the starting point in the simulations from the UMTS system. The use of a

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signal sequence K(i) or synchronization code cp that is or can be formed in such a way substantially reduces the outlay on calculating the correlation sums, that is to say for determining the signal sequence K(i) in the receiving mobile station MS for the purpose of synchronization, without the need to accept a simultaneous increase in the synchronization

5   error. Moreover, it is thereby possible to dispense with the use of expensive crystals in the receiver for the purpose of frequency stabilization.

In these simulations, the use of the following Golay sequences as partial signal sequence prove to be particularly advantageous:

A Golay sequence $X_n(k)$ of length nx=16, which can be formed using the following

10   relationship:

$$X_0 (k) = \delta (k)$$
$$X'_0 (k) = \delta (k)$$
$$X_n (k) = X_{n-1}(k) + W_n \cdot X'_{n-1} (k - D_n)$$
$$X'_n (k) = X_{n-1}(k) - W_n \cdot X'_{n-1} (k - D_n),$$

$$k = 0, 1, 2, ..., 2^{NX}-1$$
$$n = 1, 2, ..., NX$$

15   $$D_n = 2^{P_n}$$

where

$$nx=16=2^{NX}$$
$$NX=4$$

δ *(k)* Kronecker delta function,

20

-    the permutation P_1, P_2, P_3, P_4 and unit variable W_1, W_2, W_3, W_4 used to form a partial signal sequence being taken from the following set of permutation/unit variable pairs $(P_1, P_2, P_3, P_4, W_1, W_2, W_3, W_4;)$:

3201, +1-1+1+1; 3201, -1-1+1+1; 3201, +1-1-1+1; 3201, -1-1-1+1; 3201, +1-

25   1+1-1; 3201, -1-1+1-1; 3201, +1-1-1-1; 3201, -1-1-1-1; 1023, +1+1-1+1;
1023, -1+1-1+1; 1023, +1-1-1+1; 1023, -1-1-1+1; 1023, +1+1-1-1; 1023, -
1+1-1-1; 1023, +1-1-1-1; 1023,-1-1-1-1;.

A specific development of the present invention provides that the permutation $P_1, P_2,$ P_3, P_4 and unit variable W_1, W_2, W_3, W_4 used to form the partial signal sequence is taken from

30   the following set of permutation/unit variable pairs $(P_1 P_2 P_3 P_4, W_1 W_2 W_3 W_4;)$: 3201, +1-1+1+1; 3201, -1-1-1+1; 3201, -1-1+1-1; 3201, +1-1-1-1; and/or the permutation $(P_1 P_2 P_3 P_4)$ used to form the second partial signal sequence is equal to 3201. In addition, a particularly

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favorable variant implementation of the <u>present</u> invention in ASICs ~~can~~ is thereby rendered possible.

~~By means of~~ <u>Through</u> knowledge concerning the partial signal sequences in the mobile station, it is possible for the calculation of correlation sums that is required to synchronize a mobile station with a base station to be carried out in the mobile station with less outlay compared with the prior art.

In a development of the <u>present</u> invention, partial correlation sums once calculated are stored and used to calculate further correlation sums. It is, thus, possible when calculating further correlation sums to make use of partial correlation sums already calculated and so to reduce the computational outlay enormously.

The term "received signal sequence" ~~can~~ also <u>can</u> be understood as a signal sequence which is derived from a received signal by demodulation, filtering, derotation, scaling or analog-to-digital conversion, for example.

Of course, the term "determining a signal sequence" is also understood within the scope of the application as determining the temporal opposition of a signal sequence.

~~The invention is described below in more detail with the aid of various exemplary embodiments, the explanation of which is shown by the following listed figures in which:~~

<u>Additional features and advantages of the present invention are described in, and will be apparent from, the following Detailed Description of the Invention and the Figures.</u>

<div align="center">

BRIEF DESCRIPTION OF THE FIGURES

</div>

~~f~~<u>F</u>igure 1 shows a schematic <u>diagram</u> of a mobile radio network~~;~~<u>.</u>

~~f~~<u>F</u>igure 2 shows a block diagram of a radio station~~;~~<u>.</u>

~~f~~<u>F</u>igure 3 shows a conventional method for calculating correlation sums~~;~~<u>.</u>

~~f~~<u>F</u>igure 4 shows a representation of signal sequences and partial signal sequences according to the <u>teachings of the present</u> invention~~;~~<u>.</u>

~~f~~<u>F</u>igure 5 shows a schematic for the formation of the signal sequence according to the <u>teachings of the present</u> invention~~;~~<u>.</u>

~~f~~<u>F</u>igures 6, 7 and 8 show a schematic of a method for calculating a correlation sum~~;~~<u>.</u>

~~f~~<u>F</u>igures 9 and 10 show a schematic of a variant design of a method for forming the correlation sum~~, and~~<u>.</u>

~~f~~<u>F</u>igure 11 shows a block diagram of an efficient hierarchical Golay correlator.

DETAILED DESCRIPTION OF THE INVENTION

Illustrated in fFigure 1 is a cellular mobile radio network such as, for example, the GSM (Global System for Mobile Communication), which ~~comprises~~ includes a multiplicity of mobile switching centers MSC which are networked with one another and/or provide

5 access to a fixed network PSTN/ISDN. Furthermore, these mobile switching centers MSC are connected to, in each case, at least one base station controller BSC, which can also be formed by a data processing system. A similar architecture is also to be found in a UMTS (Universal Mobile Telecommunication System).

Each base station controller BSC is connected, in turn, to at least one base station BS.

10 Such a base station BS is a radio station which can use an air interface to set up a radio link to other radio stations, what are termed mobile stations MS. Information inside radio channels f which are situated inside frequency bands b can be transmitted ~~by means of~~ via radio signals between the mobile stations MS and the base station BS assigned to these mobile stations MS. The range of the radio signals of a base station substantially defines a radio cell FZ.

15 Base stations BS and a base station controller BSC can be combined to form a base station system BSS. The base station system BSS is also responsible in this case for radio channel management and/or assignment, data rate matching, monitoring the radiotransmission link, hand-over procedures and, in the case of a CDMA system, assigning the spread code set to be used, and transfers the signaling information required for this

20 purpose to the mobile stations MS.

For FDD (Frequency-Division Duplex) systems such as the GSM, it is possible in the case of a duplex system to provide for the uplink u (mobile station (transmitting unit) to the base station (receiving unit)) frequency bands differing from those for the downlink d (base station (transmitting unit) to the mobile station (receiving unit)). A ~~plurality~~ number of

25 frequency channels f can be implemented within the different frequency bands b ~~by means of~~ via an FDMA (Frequency-Division Multiple Access) method.

Within the scope of the present application, the transmission unit is also understood as a communication unit, transmitting unit, receiving unit, communication terminal, radio station, mobile station or base station. Terms and examples used within the scope of this

30 application frequently refer also to a GSM mobile radio system; however, they are not in any way limited thereto, but can easily be mapped by a person skilled in the art with the aid of the description onto other, possibly future, mobile radio systems such as CDMA systems,; in particular, wide-band CDMA systems. Data can be efficiently transmitted, separated and

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assigned to one or more specific connections and/or to the appropriate subscriber via an air interface ~~by means of~~ via multiple access methods. It is possible to make use for this purpose of time-division multiple access TDMA, frequency-division multiple access FDMA, code-division multiple access CDMA or a combination of a ~~plurality~~ number of these

5 multiple access methods.

In FDMA, the frequency band b is broken down into a ~~plurality~~ number of frequency channels f; these frequency channels are split up into time slots ts ~~by means of~~ via time division multiple access TDMA. The signals transmitted within a time slot ts and a frequency channel f can be separated ~~by means of~~ via spread codes, what is termed CDMA

10 codes cc, that are modulated in a link-specific fashion onto the data.

The physical channels thus produced are assigned to logic channels according to a fixed scheme. The logic channels are physically distinguished into two types: signaling channels (or control channels) for transmitting signaling information (or control information) and, traffic channels (TCH) for transmitting useful data.

15 The signaling channels are further subdivided into:

- broadcast channels
- common channels
- dedicated/access control channels DCCH/ACCH

The group of broadcast channels includes the broadcast control channel BCCH, to

20 which the MS receives radio information from the base station system BSS, the frequency correction channel FCCH and the synchronization channel SCH. The common control channels include the random access channel RACH. The bursts or signal sequences that are transmitted to implement these logic channels can include in this case for different purposes signal sequences K(i), what are termed correlation sequences, or signal sequences K(i) can be

25 transmitted on these logic channels for different purposes. A method for synchronizing a mobile station MS with a base station BS is explained below by way of example~~:~~. ~~d~~During a first step of the initial search for a base station or search for a cell (initial cell search procedure), the mobile station uses the primary synchronization channel (SCH (PSC)) in order to achieve a time slot synchronization with the strongest base station. This can be

30 ensured ~~by means of~~ via a matched filter or an appropriate circuit which is matched to the primary synchronization code cp that is emitted by all the base stations. In this case, all the base stations BS emit the same primary synchronization code cp of length 256.

The mobile station uses correlation to determine from a received sequence the received signal sequences K(i), using a principle which is explained in fFigures 6 to 11 and the associated description. In this case, peaks are output by the output of a matched filter for each received signal sequence of each base station located within the reception area of the

5   mobile station. The detection of the position of the strongest peak permits the determination of the timing of the strongest base station modulo of the slot length. In order to ensure a greater reliability, the output of the matched filter can be accumulated over the number of time slots in the non-coherent fashion. The mobile station therefore carries out a correlation over a signal sequence of length 256 chips as a matched-filter operation.

10   The synchronization code cp is formed in this case in accordance with a signal sequence K(i) using a principle as explained in fFigure 5 and the associated description, or can be formed in such a way or can be obtained in such a way. The signal sequence K(i) or the synchronization code cp of length 256 is formed in this case from two partial signal sequences K1(j), K2(k), of length 16 in each case, or can be formed in such a way. These

15   partial signal sequences form a partial signal sequence pair (K1(j); K2(k)) in this case.

A signal sequence K(i) obtainable in such a way can also be termed in this case a "hierarchical signal sequence" or "hierarchical correlation sequence". A partial signal sequence can also be termed a "short correlation sequence" or "constituent sequence".

In this case, at least one partial signal sequence is a Golay sequence, also termed a

20   Golay complementary sequence of length nx, denoted *here by $X=X_{NX}(k)$*. X can be formed using the following relationship:

$$X_0(k) = \delta(k)$$
$$X'_0(k) = \delta(k)$$
$$X_n(k) = X_{n-1}(k) + W_n \cdot X'_{n-1}(k - D_n)$$
$$X'_n(k) = X_{n-1}(k) - W_n \cdot X'_{n-1}(k - D_n),$$

$$k = 0, 1, 2, ..., 2^{NX}-1$$
25
$$n = 1, 2, ..., NX$$
$$D_n = 2^{P_n}$$

where

$$nx = 2^{NX}$$

δ *(k)* Kronecker delta function

30   P_n, n = 1, 2, ...NX; arbitrary permutation of the numbers $\{0, 1, 2, ..., NX\}$,

W_n weights for the partial signal sequence (+1,-1,+i or -i).

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A method of Golay and Sivaswamy for generating Golay sequences as such is also known from "Efficient Pulse compressor for Golay Complementary Sequences", Electronic Letters Vol. 27, No. 3, pp. 219.

5   W_n can, therefore, assume the values +1, -1, +i or -i, or, in particular, assume the values +1 or -1 for the purpose of generating binary Golay sequences.

Within the scope of the present application, W_n is also denoted as a unit variable. The set of the variables D_n, used for a Golay sequence, which can be calculated from the permutation P_n, is also denoted as delay matrix; the set of the selected weights W_n is also

10   denoted as a weight matrix.

For example, W = [1,-1,1,1] can be selected for the unit variable and/or the weights of the weight matrix, which means that $W_1 = 1$; $W_2 = -1$; $W_3 = 1$; $W_4 = 1$ and for the delay matrix D = [8,4,1,2], which means that $D_1=8=2^3=2^{\wedge}P1$; $D_2=4=2^2=2^{\wedge}P2$; $D_3=1=2^0=2^{\wedge}P3$; $D_4=2=2^1=2^{\wedge}P4$. The permutation or permutation matrix P=[3;2;0;1] yields the partial signal

15   sequence X_4 = (1 1 1 -1 -1 1 -1 -1 1 1 1 -1 1 -1 1 1). This sequence can be used as one of the partial signal sequences such as K1(j), for example.

By contrast with an orthogonal gold code used in conventional methods, the autocorrelation function of a signal sequence K(i) formed by two partial signal sequences generally has poorer autocorrelation properties. It has, for example, higher secondary

20   maxima and a higher r.m.s. value of the secondary minima. Moreover, UMTS link level simulations show that when such signal sequences K(i) are used in PSC for slot synchronization in the case of a frequency shift (frequency error) between the transmitter and receiver the synchronization error is generally higher by contrast with the use of an orthogonal gold code.

25   However, complicated simulation tools created specifically for this aim could be used to determine partial signal sequence pairs (K1(j);K2(k)) consisting of at least one Golay sequence, on the basis of which it is possible to form signal sequences K(i) which can be reliably determined, in particular, for synchronization between the base station and mobile station even in the case of a relatively high frequency shift between the transmitter and

30   receiver, and thus lead to a small synchronization error. In this case, a frequency shift of 10 kHz was also the starting point in the simulations for the UMTS system. The use of a signal sequence K(i) or synchronization code cp that is or can be formed in such a way substantially reduces the outlay on calculating the correlation sums, that is to say on

determining the signal sequence K(i) in the receiving mobile station MS for the purpose of synchronization, without the need to accept a simultaneous increase in the synchronization error. Moreover, it is also possible to dispense with the use of expensive crystals in the receiver for the purpose of frequency stabilization.

5   The calculation of the autocorrelation function as a function of the frequency error proved to be particularly suitable in the case of the simulations for the purpose of assessing the synchronization properties of a signal sequence K(i) formed by a permutation-unit variable pair.

The calculation of the autocorrelation function taking account of a frequency shift

10   between the transmitting and receiving units can also be carried out in this case in accordance with the following formula:

$$a(\kappa) = \text{ABS}\left(\sum_{i=0}^{n-1-\kappa} K(i) \bullet [K(i+\kappa) \bullet \exp(j \bullet 2\pi \bullet f_d \bullet i \bullet t_a))]\right)^*$$

15   κ shift

n   length of the sequence

i   index

f_d frequency shift

t_a sampling interval

20   []*   denotes the complex conjugate

In this case, the values $a(\kappa)$ can be calculated for $\kappa = 0..n-1$. If the result is a ~~plurality~~ number of partial signal sequence pairs which lead to an equally good ratio of principal maximum to the maximum secondary maximum in the autocorrelation function of the

25   resulting signal sequence K(i), the partial signal sequence pairs which lead to a lower r.m.s. value of the secondary maxima can be selected in what follows. In this case, the ratio of the principal maximum to the maximum secondary maximum is to be as large as possible, and the r.m.s. value of the secondary minima is to be as small as possible. By using subsequent link level simulations on the UMTS system, for example, it is possible to determine partial

30   signal sequence pairs which in the case of frequency errors of 0 kHz and 5 KHz and 10 kHz surprisingly behave with regard to the synchronization error as effectively as a conventional

orthogonal gold code, which is not hierarchically designed and is known to have very good properties for synchronization.

In addition to the autocorrelation function, the following criteria can also be used to select partial signal sequence pairs (K1(j);K2(k)):

- Missed detection rate: select the partial signal sequence pairs by comparing the missed detection rate when carrying out complete simulations.

- Detection probabilities for a given frequency error and a given SNR in the case of AWGN channels.

It was possible using the complicated simulations to determine a set of Golay sequences of length 16, described by a set of permutation/unit variable pairs which is specified in one and/or more of claims 1, 2, 3 or 4 on the basis of which it is possible to form signal sequences K(i) which have a small synchronization error both for a frequency shift of zero between the transmitter and receiver and for a larger frequency shift in the case of use for synchronization purposes. This leads to a preferred selection of permutation/unit variable pairs from which

partial signal sequences and, finally, signal sequences K(i) can be obtained or formed.

In one variant design of the present invention, at least one partial signal sequence is a Golay sequence in particular of length 16, optimized with regard to the secondary maxima of the autocorrelation function even in the case of frequency errors.

It turned out to be advantageous, in the case of the simulations explained above, to use a signal sequence K(i) based on a partial signal sequence, the permutation P_1, P_2, P_3, P_4 and complex unit variable W_1, W_2, W_3, W_4 used to form the partial signal sequence being taken from the following set of permutation/unit variable pairs (P_1, P_2, P_3, P_4, W_1, W_2, W_3, W_4;):

0213,+j+j+j-1; 0213,-j+j+j-1; 0213,+1-j+j-1; 0213,-1-j+j-1;

0213,+1+j-j-1; 0213,-1+j-j-1; 0213,+j-j-j-1; 0213,-j-j-j-1;

0213,+j+j+j+1; 0213,-j+j+j+1; 0213,+1-j+j+1; 0213,-1-j+j+1;

0213,+1+j-j+1; 0213,-1+j-j+1; 0213,+1-j-j+1; 0213,-j-j-j+1;

3120,+1-j+j-1; 3120,-1-j+j-1; 3120,+1+j-j-1; 3120,-1+j-j-1;

3120,+1+j+j+j; 3120,-1-j+j+j; 3120,+1-j-j+j; 3120,-1-j-j+j;

3120,+1+j+j-j; 3120,-1+j+j-j; 3120,+1-j-j-j; 3120,-1-j-j-j;

3120,+1-j+j+1; 3120,-1-j+j+1; 3120,+1+j-j+1; 3120,-1+j-j+1;

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It proved to be particularly advantageous in the case of the simulations explained above to use a signal sequence K(i) based on a partial signal sequence, the permutation P_1, P_2, P_3, P_4 and binary unit variable W_1, W_2, W_3, W_4 used to form the partial signal sequence being taken from the following set of permutation/unit variable pairs (P_1, P_2, P_3, P_4, W_1, W_2, W_3, W_4):

5

3201, +1-1+1+1; 3201, -1-1+1+1; 3201, +1-1-1+1; 3201, -1-1-1+1; 3201, +1-1+1-1; 3201, -1-1+1-1; 3201, +1-1-1-1; 3201, -1-1-1-1; 1023, +1+1-1+1; 1023, -1+1-1+1; 1023, +1-1-1+1; 1023, -1-1-1+1; 1023, +1+1-1-1; 1023, -1+1-1-1; 1023, +1-1-1-1; 1023, -1-1-1-1;.

10   It proved to be particularly advantageous in the case of the simulations explained above to use a signal sequence K(i) based on a partial signal sequence, the permutation P_1, P_2, P_3, P_4 and binary unit variable W_1, W_2, W_3, W_4 used to form the partial signal sequence being taken from the following set of permutation/unit variable pairs (P_1, P_2, P_3, P_4, W_1, W_2, W_3, W_4):

15   3201, +1-1+1+1; 3201, -1-1-1+1; 3201, -1-1+1-1; 3201, +1-1-1-1; and the permutation (P_1, P_2, P_3, P_4) used to form the second partial signal sequence is equal to 3201.

As already explained above-, in addition to the permutation/unit variable representation, it is also possible to represent the Golay sequences by specifying the delay matrix and the weight matrix. The sequence with real weights which is specified as particularly advantageous in the first place above, the sequence (3201,+1-1+1+1) specified by the parameters (P_1, P_2, P_3, P_4, W_1, W_2, W_3, W_4) is therefore defined by the delay matrix $D = [8, 4, 1, 2]$ and the weight matrix $W = [1, -1, 1, 1]$.

Furthermore, the Golay sequence can also be represented explicitly by specifying the individual elements, the result for the above-named Golay sequence of length 16 being in this case:

25

$K1 = <+1,+1,+1,-1,-1,+1,-1,-1,+1,+1,+1,-1,+1,-1,+1,+1>$

A further equivalent representation follows in the case of the mapping from +1 to 0 and -1 to 1 that is frequently used in the literature. The sequence is then defined by:

$<0,0,0,1,1,0,1,1,0,0,0,1,0,1,0,0>$

30   Thus, if Golay sequences of length 16 are used as partial signal sequences (constituent sequences) for the PSC of UMTS, $W_n = 1, -1, i -i$ being permitted as weights, an arbitrary permutation from $D_n = \{1,2,4,8\}$ being permitted as delays, the result is more than 2_{12} different possibilities for each of the two constituent sequences, that is to say a total of 2_{24} possibilities.

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In accordance with ~~patent claims 1, 2, 3, or 4 the scope of the~~ certain embodiments, the present invention includes approximately 10 to 10^2 permutation/unit variable pairs. The selected permutation/unit variable pairs therefore form only a very small subset of the fundamentally possible set of permutation/unit variable pairs that can be used to form 16-digit Golay sequences.

Figure 2 shows a radio station which can be a mobile station MS, consisting of an operating unit or interface unit MI, a control device STE, a processing device VE, a power supply device SVE, a receiving device EE and, if appropriate, a transmitting device SE.

The control device STE essentially ~~comprises~~ includes a program-controlled microcontroller MC, which can access memory chips SPE by writing and reading. The microcontroller MC controls and monitors all essential elements and functions of the radio station.

The processing device VE can also be formed by a digital signal processor DSP, which can, likewise, access memory chips SPE. Addition and multiplication ~~means~~ can ~~also~~ be ~~realized by means of~~ effected via the processing device VE.

The program data required for controlling the radio station and the communication cycle, as well as, in particular, the signaling procedures, and information produced during the processing of signals are stored in the volatile or nonvolatile memory chips SPE. Moreover, signal sequences K(i) which are used for correlation purposes, and intermediate results of correlation sum calculations can also be stored therein. The signal sequences K(i) within the scope of the present invention can ~~thus~~ be stored in the mobile station and/or the base station. It is also possible for one or more of the permutation/unit variable pairs set forth above or partial signal sequences or partial signal sequence pairs (K1(j);K2(k)) derived therefrom to be stored in the mobile station and/or the base station. It is also possible for a signal sequence K(i) to be formed from a partial signal sequence pair (K1(j);K2(k)) and/or a partial signal sequence to be formed from a permutation/unit variable pairs in the mobile station and/or the base station.

In particular, it is possible to store in a base station, or in all the base stations in a system, a signal sequence K(i) which is emitted at fixed or variable intervals for synchronization purposes. The partial signal sequence pair (K1(j);K2(k)), from which the signal sequence K(i) stored in the base station can be formed, is stored in the mobile station MS and is used to synchronize the mobile station with a base station in order to calculate the correlation sum favorably in terms of computation outlay.

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The storage of the signal sequences or the partial signal sequences can also be performed by storing appropriate information in arbitrarily coded form, and can be implemented with the aid of ~~means for~~ storage <u>parts</u> such as, for example, volatile and/or nonvolatile memory chips or ~~by means of~~ <u>via</u> appropriately designed adder or multiplier inputs or appropriate hardware configurations which have the same effect.

The high-frequency section HF ~~comprises~~ <u>includes</u>, if appropriate, the transmitting device SE, with a modulator and an amplifier V, and a receiving device EE with a demodulator and, likewise, an amplifier. The analog audio signals and the analog signals originating from the receiving device EE are converted ~~by means of~~ <u>via</u> analog-to-digital conversion into digital signals and processed by the digital signal processor DSP. After processing, the digital signals are converted, if appropriate, by digital-to-analog conversion into analog audio signals or other output signals and analog signals that are to be fed to the transmitting device SE. Modulation or demodulation, respectively, is carried out for this purpose, if appropriate.

The transmitting device SE and the receiving device EE are fed with the frequency of a voltage-controlled oscillator VCO via the synthesizer SYN. The system clock for timing processor devices of the radio station can also be generated ~~by means of~~ <u>via</u> the voltage-controlled oscillator VCO.

An antenna device ANT is provided for receiving and for transmitting signals via the air interface of a mobile radio system. The signals are received and transmitted in what are termed bursts that are pulsed over time in the case of some known mobile radio systems such as the GSM (Global System for Mobile Communication).

The radio station may also be a base station BS. In this case, the loudspeaker element and the microphone element of the operating unit MMI are replaced by a link to a mobile radio network~~,~~; for example~~,~~ via a base station controller BSC or a switching device MSC. The base station BS has an appropriate multiplicity of transmitting and receiving devices, respectively, in order to exchange data simultaneously with a ~~plurality~~ <u>number</u> of mobile stations MS.

The received signal sequence E(l), which can also be a signal sequence derived from a received signal, of length w is illustrated in ~~f~~<u>F</u>igure 3. In order to calculate a first correlation sum S0 in accordance with the formula specified at the beginning, elements of a first section of this received signal sequence E(l) are multiplied in pairs by the corresponding elements of

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the signal sequence K(i) of length n, and the length of the resulting partial results is added to the correlation sum S0.

In order to calculate a further correlation sum S1, as illustrated in the fFigure 3, the signal sequence K(i) is shifted to the right by one element, and the elements of the signal

5 sequence K(i) are multiplied in pairs by the corresponding elements of the signal sequence E(l), and the correlation sum S1 is formed again by summing the partial results produced.

The pairwise multiplication of the elements of the signal sequence by corresponding elements of the received signal sequence, and the subsequent summation can also be described in vector notation as the formation of a scalar product, if the elements of the signal

10 sequence and the elements of the received signal sequence are respectively aligned to form a vector of a Cartesian coordinate system:

$$S0 = \begin{pmatrix} K(0) \\ \vdots \\ K(i) \\ \vdots \\ K(n-1) \end{pmatrix} * \begin{pmatrix} E(0) \\ \vdots \\ E(i) \\ \vdots \\ E(n-1) \end{pmatrix} = K(0)*E(0)+...+K(i)*E(i)+...+K(n-1)*E(n-1)$$

$$S1 = \begin{pmatrix} K(0) \\ \vdots \\ K(i) \\ \vdots \\ K(n-1) \end{pmatrix} * \begin{pmatrix} E(1) \\ \vdots \\ E(i+1) \\ \vdots \\ E(n) \end{pmatrix} = K(0)*E(1)+...+K(i)*E(i+1)+...+K(n-1)*E(n)$$

15

In the correlation sums S thus determined, it is possible to search for the maximum and compare the maximum of the correlation sums S with a prescribed threshold value and thus determine whether the prescribed signal sequence K(i) is included in the received signal

20 E(l) and if so where it is located in the received signal E(l) and thus two radio stations are synchronized with one another or data are detected on to which an individual spread code has been modulated in the form of a signal sequence K(i).

Represented again in fFigure 4 is the received signal sequence E(l) and, as correlation sequence a signal sequence K(i) which is based on the partial signal sequences K1(j), K2(k).

45

Represented in fFigure 5 is the formation of a signal sequence K(i) which is based on two partial signal sequences K2(k) of length n2 and K1(j) of length n1. For this purpose, the partial signal sequence K2(k) is repeated n1 times and modulated in the process by the partial signal sequence K1(k). The formation of the signal sequence K(i) can also be expressed

5   mathematically by the following formula:

$$K(i) = K2(i \bmod n2) * K1(i \operatorname{div} n2), \text{ for } i = 0 ...n1*n2-1$$

mod denotes the integral remainder of a division, and div denotes the integral result of a division.

This is illustrated by a sequence f2 which consists of the repeated, sequentially

10   mapped partial signal sequences K2(k), and a sequence f1 which is mapped by an extended partial signal sequence K1(j) over the sequence f2.

The new signal sequence K(i) of length n is produced by multiplying the elements of the sequence f2 by the corresponding elements, mapped over the sequence f2, of the sequence f1. This generation of a signal sequence K(i) is represented once again at the bottom of the

15   illustration with the aid of an example of two binary partial signal sequences of length 4.

The present invention is not, of course, limited to partial signal sequences of length 4 or signal sequences of length 16. Neither is the present invention limited to the mathematical description used above.

For example, the following representation for partial signal sequences of length 16 or

20   signal sequences of length 256 correspond in content to the mathematical representation used above, and is therefore likewise contained in the present invention:

For example, if use is made for K1 of the Golay sequence, described above as particularly favorable, with the permutation/unit variable representation (3201 , +1-1+1+1) or the explicit representation <+1,+1,+1,-1,-1,+1,-1,-1,+1,+1,+1,-1,+1-1,+1,+1>, and for K2 of a

25   sequence a consisting of 16 elements, it is also possible to write the repeated, sequentially mapped partial signal sequences K2 and a, which are modulated with the value of the respective element of the sequence K1, as follows:

K = <a, a, a, -a, -a, a, -a, -a, a, a, a, -a, a, -a, a, a>

Signal sequences K(i) formed in such a way can be used for simplified calculation of

30   correlation sums of these signal sequences K(i) with received signal sequences E(l)._The signal sequence of length 256 thus formed can, for example, be emitted for synchronization purposes as primary synchronization code cp of length 256.

A schematic of such a simplified calculation of correlation sums S, which is, therefore, also faster and more favorable in terms of outlay, is represented in fFigures 6 to 8, which are examined below.

The first step is to form a partial correlation sum TS(z). For this purpose, for

5   example, the correlation sum of the second partial signal sequence K2(k) with the corresponding section of the received signal sequence E(l) is formed for the first element of the partial correlation sequence TS(0).

$$TS(0) = \begin{pmatrix} K2(0) \\ \vdots \\ K2(k) \\ \vdots \\ K2(n2-1) \end{pmatrix} * \begin{pmatrix} E(0) \\ \vdots \\ E(k) \\ \vdots \\ E(n2-1) \end{pmatrix} = K2(0)*E(0)+...+K2(k)*E(k)+...+K2(n2-1)*E(n2-1)$$

10   As illustrated, for the second element of the partial correlation sum sequence TS(1) the second partial signal sequence K2(k) is shifted by one element, and the correlation sum with the corresponding element of the received signal sequence E(l) is likewise formed, etc.

$$TS(1) = \begin{pmatrix} K2(0) \\ \vdots \\ K2(k) \\ \vdots \\ K2(n2-1) \end{pmatrix} * \begin{pmatrix} E(1) \\ \vdots \\ E(k+1) \\ \vdots \\ E(n2) \end{pmatrix} = K2(0)*E(1)+...+K2(k)*E(k+1)+...+K2(n2-1)*E(n2)$$

15

The n-th element of the partial correlation sum sequence TS(n1*n2-1) is calculated correspondingly after n-1 shifts of the second partial signal sequence K2(k) with respect to the received signal sequence E(l).

20

$$TS(n-1) = \begin{pmatrix} K2(0) \\ \vdots \\ K2(k) \\ \vdots \\ K2(n2-1) \end{pmatrix} * \begin{pmatrix} E(n-1) \\ \vdots \\ E(k+n-1) \\ \vdots \\ E(n2+n-2) \end{pmatrix} =$$

$$= K2(0)*E(n-1)+...+K2(k)*E(k+n-1)+...+K2(n2-1)*E(n2+n-2)$$

47

The partial correlation sum sequence TS(z) thus produced is represented at the top in fFigure 7. Each n2-th element is now selected from this partial correlation sum sequence and multiplied by the corresponding element of the first partial signal sequence K1(j) in pairs.

Combining the selected elements of the partial correlation sum sequence TS(z) and

5   the first partial signal sequence K1(k) to form vectors in each case produces the first correlation sum S0 ~~by means of~~ via the scalar product of these two vectors.

$$
S0 = \begin{pmatrix} K1(0) \\ \vdots \\ K1(j) \\ \vdots \\ K1(n1-1) \end{pmatrix} * \begin{pmatrix} TS(0) \\ \vdots \\ TS(j*n2-1) \\ \vdots \\ TS((n1-1)*n2-1) \end{pmatrix} = K1(0)*TS(0)+...+K1(j)*TS(j*n2-1)+...
$$

10   Figure 7 shows at the bottom the corresponding calculation of further correlation sums S1 and S2, respectively, through the selection of n2-th elements situated one or two to the right of the initially selected elements:

$$
S1 = \begin{pmatrix} K1(0) \\ \vdots \\ K1(j) \\ \vdots \\ K1(n1-1) \end{pmatrix} * \begin{pmatrix} TS(1) \\ \vdots \\ TS(j*n2) \\ \vdots \\ TS((n1-1)*n2) \end{pmatrix} = K1(0)*TS(0)+...+K1(j)*TS(j*n2)+...
$$

15

By storing partial correlation sums TS once calculated, it is possible to have recourse to them again when later calculating further correlation sums, and thus to dispense with the corresponding computational steps.

Depending on the design variant, it is possible either firstly to calculate the complete

20   partial correlation sum sequence TS(z) over the entire received signal sequence E(l), and then to calculate the individual correlation sums, or not to calculate the corresponding additionally required partial correlation sums until required for the purpose of calculating a new correlation sum.

Figure 8 shows, once again, the method consisting of two steps, for calculating

25   correlation sums S, this time with the aid of the example, represented in fFigure 5, of two binary partial signal sequences of length 4.

48

In a first step, the partial correlation sums TS(z) of the second partial signal sequence K2(k) +-++ are calculated with corresponding sections of the received signal sequence E(l) and, in a second step, each fourth element of the partial correlation sum sequence TS(z) thus produced is then selected, multiplied by the corresponding element of the first partial signal sequence K1(j) +++-, and summed to form the correlation sequence S0.

The bold lines in this case represent the calculation steps that have to be carried out anew for calculation of a further correlation sum S1 for the case in which the remaining partial correlation sums TS have already previously been calculated and stored.

This variant design can be carried out as efficiently as possible in terms of storage if each n2-th partial correlation sum is firstly calculated. The samples are buffered for this purpose.

Figures 9 to 10 present another variant design for simplified calculation of correlation sums S with the aid of the example, already mentioned above, of two binary partial signal sequences of length 4.

The first step here is to select each 4th element of the received signal sequence E(l) and to form the partial correlation sum sequence TS(z) of the elements thus selected with the partial signal sequence K1(k). Four sequential elements are respectively selected from the partial correlation sum sequence TS(z) thus produced and multiplied in pairs by corresponding elements of the partial signal sequence K2(k), and the resulting partial results are summed to form the correlation sum S. Once again, here, the bold lines represent the additionally required steps for calculating a further correlation sum S1 for the case in which the other partial correlation sums TS have already been calculated and stored before.

Figure 10 shows, once again, the calculation of a first correlation sum S0, in the case of which, firstly, each 4th element of the received signal sequence E(l) is selected, these elements are multiplied by corresponding elements of the first partial signal sequence K1(k) +++-, and the partial correlation sum TS(0) is calculated by summing the partial results. In a second step, the first 4 sequential elements of the partial correlation sum sequence TS(z) are multiplied by the corresponding elements of the second partial signal sequence K2(k) +-++, and the partial results produced are summed to form the correlation sum S0.

This variant design requires less storage for buffering the partial correlation sums when the sums are calculated successively.

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A further refinement of the present invention utilizes the regular (fast periodic) structure, caused by the regular design principle of the signal sequence K(i), of the aperiodic autocorrelation function of this signal sequence. ~~This means that~~ As such, when a signal is being sought, not only is a principal maximum produced, but secondary maxima also occur at

5   regular intervals. The regularity of the position of the maxima can be utilized to accelerate the search for the signal sequence in the received signal sequence. As soon as a secondary maxima has been found, it is possible to predict the position of the other maxima on the basis of the periodicity. That is to say the correlation sum is calculated only at these points. The principal maximum can be detected quickly in this way. However, the supposed secondary

10   maximum can also be only a randomly increased value (because of the noise component). In this case, no maximum will actually be found at the potential points of the expected principal maximum. Consequently, the hypothesis is rejected in this case and the calculation is continued conventionally.

However, the regularity, caused by the design principle of the signal sequences, of the

15   secondary maxima can also be utilized to eliminate and correct interfering secondary maxima in the correlation result. After the detection of the maximum, the secondary maxima can be calculated therefrom and this value can be subtracted from the corresponding correlation results. The correlation result of a (hypothetical) sequence with a perfect autocorrelation function is obtained in this way. This results in a greatly simplified calculation owing to the

20   regularity of the secondary maxima.

In ~~variant designs~~ various embodiments of the present invention, efficient Golay correlators are used to calculate scalar products, correlation sums and/or partial correlation sums.

Figure 11 shows an efficient hierarchical correlator for signal sequences, Golay

25   sequences X,Y of length nx and ny respectively being used as constituent sequences K1, K2. The correlator consists of two series-connected matched filters (~~f~~Figure 11a) which are respectively formed as efficient Golay correlators. Figure 11b~~)~~ shows the matched filter for the sequence X, and ~~f~~Figure 11 c~~)~~ shows the matched filter for the sequence Y.

The following designations apply in ~~f~~Figure 11 b~~)~~:

30           $n = 1, 2, ...NX$

             ny   length of sequence Y

             nx   length of sequence X

             NX   with $nx = 2^{NX}$

50

DX_n $DX_n = 2^{PX_n}$

PX_n permutation of the numbers {0, 1, 2, ..., NX-1}

for the partial signal sequence X

WX_n weights for the partial signal sequence X

from (+1,-1,+i or -i).

The following designations apply in fFigure 11 c}:

n = 1, 2, ...NY

ny   length of sequence Y

NY   with ny=2^{NY}

DY_n $DY_n = 2^{PY_n}$

PY_n permutation of the numbers {0, 1, 2, ..., NY-1} for the partial

signal sequence Y

WY_n weights for the partial signal sequence Y from (+1,-1,+i or -i)

Moreover, the following definitions and designations are valid in these variant designs:

$a_n(k)$ and $b_n(k)$ are two complex sequences of length 2^N,

$\delta(k)$ is the Kronecker delta function

k is an integer representing time,

n is the iteration number,

D_n is the delay,

P_n, n = 1, 2, ..., N, is an arbitrary permutation of the numbers {0, 1, 2, ..., N-1},

W_n can assume the values +1, -1, +i, -i as weights and is also designated as unit variable.

The correlation of a Golay sequence of length 2^N can now be carried out efficiently as follows:

The sequences $R_a(0)(k)$ and $R_b(0)(k)$ are defined as $R_a(0)(k) = R_b(0)(k) = r(k)$, r(k) being the received signal or the output of another correlation stage.

The following step is executed N times: n runs from 1 to N:

Calculate

$$R_a^{(n)}(k) = W^*_n * R_b^{(n-1)}(k) + R_a^{(n-1)}(k- D_n)$$

and

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$$R_b^{(n)}(k) = W^*_n * R_b^{(n-1)}(k) + R_a^{(n-1)}(k - D_n),$$

W^*_n designating the complex conjugate of W_n. If the weights W are real, W^*_n is identical to W_n.

$R_a^{(N)}(k)$ is then the correlation sum to be calculated.

5   An efficient Golay correlator for a PSC code of length 256 (2^8) chips in the receiver generally has $2 \cdot 8 - 1 = 15$ complex adders. With the combination of hierarchical correlation and efficient Golay correlator, a hierarchical code-, described by two constituent sequences X and Y-, of length 256 ($2^4 \cdot 2^4$) requires only $2 \cdot 4 - 1 + 2 \cdot 4 - 1 = 14$ complex adders (even when use is made of four-valued constituent sequences). This reduces by 7% the outlay on calculation, which is very high for the primary synchronization in CDMA mobile radio systems.

     Specified below-, marked in each case by dividing dashes-, of variant designs of the present invention the implementation of which are within the activity of a person skilled in the art given knowledge of the present application:

     -      to form a code sequence of length 2^{NX+NY}, two constituent Golay sequences of length $nx = 2^{NX}$ and $ny = 2^{NY}$ are used and are hierarchically constructed as described above.

     -      +1 and -1 are used as weights for the constituent Golay sequences, binary sequences thereby being produced.

     -      +1, -1, i or -i are used as weights for the constituent Golay sequences, four-valued sequences thereby being produced.

     -      Real Golay sequences are used.

     -      Complex Golay sequences are used.

     -      Two constituent Golay sequences of equal length are used.

     -      Two complementary Golay sequences are used.

     -      Only one efficient Golay correlator, with programmable delays, if appropriate, is used for optional calculation of one or both complementary Golay sequences.

     -      A sequence is used as described, but additional values are also inserted; these values must be accumulated as usual during the calculation. The remainder of the calculation can, however, be carried out efficiently as described. This permits the generation of sequences of arbitrary length.

     -      Two constituent sub-sequences are used.

     -      A ~~plurality~~ number of constituent sub-sequences are used.

52

- A Golay sequence is used only for some of the sub-sequences.

- These sequences are used for the synchronization channel in UMTS.

- Constituent Golay sequences optimized for frequency error are used.

- Two series-connected filters are used to calculate the correlation, one being a matched filter matched to the Golay sequence X, the other being a matched filter matched to the Golay sequence Y with spread delays $ny \cdot DX_n$.

- Two series-connected filters are used to calculate the correlation, one being a matched filter matched to the Golay sequence X, and the other being a matched filter matched to the Golay sequence Y with spread delays $ny \cdot DX_n$, and the output signals of the filters being calculated in accordance with the efficient Golay correlator algorithm.

- The efficient Golay correlation algorithm is used to calculate the partial correlation sums and the algorithm for the hierarchical correlation is used to determine the overall correlation.

The present invention is not limited to radio transmission systems, but can also be employed in the use of other transmission methods, for example, acoustic method (ultrasound) in particular, for the purposes of sonography, or optical methods, for example infrared measurement using lidar principles. A further field of application is the investigation of changes in the spectral composition of backscattered signals.

Indeed, although the present invention has been described with reference to specific embodiments, those of skill in the art will recognize that changes made be made thereto without departing from the spirit and scope of the invention as set forth in the hereafter appended claims.

53

ABSTRACT OF THE DISCLOSURE .

~~Abstract~~

Method for forming and determining a signal sequence, a synchronization method, a transmitting unit and a receiving unit , including the formation ~~Formation~~ of signal sequences which are based on partial signal sequences, the second partial signal sequence being repeated and modulated in the process by the first partial signal sequence, and at least one of the signal sequences being a Golay sequence. ~~Use,~~ and use of these partial signal sequences for the purpose of simplified calculation of correlation sums in a two-stage calculation method, one partial correlation sum sequence being calculated first.

5

10

~~Figure 5~~

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Description

Method for synchronizing a base station with a mobile
station, a base station and a mobile station

5   The invention relates to a method for synchronizing a
base station with a mobile station, a base station and
a mobile station.

10   In signal transmission systems, such as mobile radio
systems, it is necessary for one of the communication
partners (first transmission unit) to detect specific
fixed signals which are emitted by another
communication partner (second transmission unit). These
15   can be, for example, what are termed synchronization
bursts for synchronizing two synchronization partners
such as radio stations, for example, or what are termed
access bursts.

20   In order to detect or identify such received signals
reliably by contrast with the ambient noise, it is
known to correlate the received signal continuously
with a prescribed signal sequence over a fixed time
duration, and to form the correlation sum over the time
25   duration of the prescribed signal sequence. The range
of the received signal, which yields a maximum
correlation sum, corresponds to the signal being
searched for. Connected upstream, as what is termed a
training sequence, of the synchronization signal from
30   the base station of a digital mobile radio system, is,
for example, a signal sequence which is detected or
determined in the mobile station in the way just
described by correlation with the stored signal
sequence. The mobile stations can thus be synchronized
35   with the base station.

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Such correlation calculations are also necessary in the base station, for example in the case of random-access-channel (RACH) detection. Moreover, a correlation

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calculation is also carried out to determine the channel pulse response and the signal propagation times of received signal bursts.

5   The correlation sum is calculated as follows in this case:

$$Sm = \sum_{i=0}^{n-1} E(i+m) * K(i)$$

10   E(i) being a received signal sequence derived from the received signal, and K(i) being the prescribed signal sequence, i running from 0 to n-1. The correlation sum Sm is calculated sequentially for a plurality of temporally offset signal sequences E(i) obtained from
15   the received signal, and then maximum value of Sm is determined. If k sequential correlation sums are to be calculated, the outlay on calculation is k * n operations, the multiplication and addition being counted together as one operation.
20

The calculation of the correlation sums is therefore very complicated and, particularly in real time applications such as voice communication or radio telephony or in CDMA systems, requires powerful, and
25   therefore expensive processors which have a high power consumption during calculation. For example, a known signal sequence of length 256 chips (a transmitted bit is also termed a chip in CDMA) is to be determined for the purpose of synchronizing the UMTS mobile radio
30   system, which is being standardized. The sequence is repeated every 2560 chips. Since the mobile station initially operates asynchronously relative to the chip clock, the received signal must be oversampled in order

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still to retain an adequate signal even given an unfavorable sampling situation. Because of the sampling of the I and Q components, this leads to 256*2560*2*2 = 2621440 operations.

5

WO 96 39749 A discloses transmitting a synchronization sequence, a chip of the sequence itself being a sequence.

The use of Golay sequences as an alternative to PN sequences is known from "Srdjan Budisin: Golay Complementary Sequences are Superior to PN Sequences, Proceedings of the International Conference on Systems
5 Engineering, US, New York, IEEE, Vol.-,1992, pages 101-104, XP 000319401 ISBN: 0-7803-0734-8".

It is the object of the invention to specify methods for synchronizing a base station with a mobile station,
10 a base station and a mobile station which permits a base station to be synchronized with a mobile station in a way which is reliable and favorable in terms of outlay.

15 The object is achieved by means of the features of the independent patent claims. Developments are to be gathered from the subclaims.

The invention is based firstly on the idea of using for
20 synchronization purposes signal sequences which can be formed by repeating a second partial signal sequence of length n2 n1 times, in which process the first partial signal sequence (length n1) is used for modulation and at least one of the partial signal sequences is a Golay
25 sequence also often termed a Golay complementary sequence. It is thereby possible to form signal sequences which can be determined easily when they are contained in a received signal sequence. The use of Golay sequences is advantageous, in particular, because
30 a very effective algorithm is known for this purpose for calculating the correlation.

The invention is also based on the findings that the use of two partial signal sequences of equal length

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permits correlation sums to be calculated quickly and favorably in terms of outlay.

Thus, for example, given the use of a hierarchical correlation sequence of length 256, which is constructed from 2 constituent Golay sequences of length 16, the computational outlay for the PSC

5   (primary synchronization channel) of a UMTS system can be reduced by contrast with a conventional implementation by means of a Golay sequence of length 256 from 15 to 14 additions per calculated correlation output value.

10

However, by contrast with an orthogonal gold code used in conventional methods, the autocorrelation function of a signal sequence K(i) formed by two partial signal sequences generally has poorer autocorrelation

15 properties. It has, for example, higher secondary maxima and a higher r.m.s. value of the secondary minima. Moreover, UMTS link level simulations show that when such signal sequences K(i) are used in PSC for slot synchronization in the case of a frequency shift

20 (frequency error) between the transmitter and receiver the synchronization error is generally higher than when an orthogonal gold code is used.

However, complicated simulation tools created

25 specifically for this aim could be used to determine partial signal sequence pairs (K1(j);K2(k)) consisting of at least one Golay sequence, on the basis of which it is possible to form signal sequences K(i) which can be reliably determined, in particular even given a

30 higher frequency shift between the transmitter and receiver, and thus lead to a small synchronization error. In this case, a frequency shift of 10 kHz was also the starting point in the simulations from the UMTS system. The use of a signal sequence K(i) or

35 synchronization code cp that is or can be formed in

such a way substantially reduces the outlay on calculating the correlation sums, that is to say for determining the signal sequence K(i) in the receiving mobile station MS for the purpose of synchronization, without the need to accept a simultaneous increase in the synchronization error. More-

over, it is thereby possible to dispense with the use of expensive crystals in the receiver for the purpose of frequency stabilization.

5   In these simulations, the use of the following Golay sequences as partial signal sequence prove to be particularly advantageous:

A Golay sequence $X_n(k)$ of length nx=16, which can be
10   formed using the following relationship:

$$X_0(k) = \delta(k)$$
$$X'_0(k) = \delta(k)$$
$$X_n(k) = X_{n-1}(k) + W_n \cdot X'_{n-1}(k - D_n)$$
$$X'_n(k) = X_{n-1}(k) - W_n \cdot X'_{n-1}(k - D_n),$$

$$k = 0, 1, 2, \ldots, 2^{NX}-1$$
15   $$n = 1, 2, \ldots, NX$$
$$D_n = 2^{P_n}$$

where
        $$nx=16=2^{NX}$$
        $$NX=4$$
20       $\delta(k)$ Kronecker delta function,
-        the permutation P_1, P_2, P_3, P_4 and unit variable W_1, W_2, W_3, W_4 used to form a partial signal sequence being taken from the following set of permutation/unit variable pairs (P_1, P_2, P_3, P_4, W_1, W_2, W_3, W_4):
25   3201, +1-1+1+1; 3201, -1-1+1+1; 3201, +1-1-1+1; 3201, -1-1-1+1; 3201, +1-1+1-1; 3201, -1-1+1-1; 3201, +1-1-1-1; 3201,
-1-1-1-1; 1023, +1+1-1+1; 1023, -1+1-1+1; 1023, +1-1-1+1; 1023, -1-1-1+1; 1023, +1+1-1-1; 1023, -1+1-1-1;
30   1023, +1-1-1-1; 1023, -1-1-1-1; .

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A specific development of the invention provides that
the permutation P_1, P_2, P_3, P_4 and unit variable W_1, W_2, W_3,
W_4 used to form the partial signal sequence is taken
from

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the following set of permutation/unit variable pairs $(P_1\ P_2\ P_3\ P_4,\ W_1\ W_2\ W_3\ W_4;)$: 3201, +1-1+1+1; 3201, -1-1-1+1; 3201, -1-1+1-1; 3201, +1-1-1-1; and/or the permutation $(P_1\ P_2\ P_3\ P_4)$ used to form the second partial signal sequence is equal to 3201. In addition, a particularly favorable variant implementation of the invention in ASICs can is thereby rendered possible.

By means of knowledge concerning the partial signal sequences in the mobile station, it is possible for the calculation of correlation sums that is required to synchronize a mobile station with a base station to be carried out in the mobile station with less outlay compared with the prior art.

In a development of the invention, partial correlation sums once calculated are stored and used to calculate further correlation sums. It is thus possible when calculating further correlation sums to make use of partial correlation sums already calculated and so to reduce the computational outlay enormously.

The term "received signal sequence" can also be understood as a signal sequence which is derived from a received signal by demodulation, filtering, derotation, scaling or analog-to-digital conversion, for example.

Of course, the term "determining a signal sequence" is also understood within the scope of the application as determining the temporal opposition of a signal sequence.

The invention is described below in more detail with the aid of various exemplary embodiments, the explanation of which is shown by the following listed

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figures in which:

figure 1 shows a schematic of a mobile radio network,

5   figure 2 shows a block diagram of a radio station,

figure 3 shows a conventional method for calculating correlation sums,

figure 4 shows a representation of signal sequences and partial signal sequences according to the invention,

figure 5 shows a schematic for the formation of the signal sequence according to the invention,

figures 6, 7 and 8 show a schematic of a method for calculating a correlation sum,

figures 9 and 10 show a schematic of a variant design of a method for forming the correlation sum, and

figure 11 shows a block diagram of an efficient hierarchical Golay correlator.

Illustrated in figure 1 is a cellular mobile radio network such as, for example, the GSM (Global System for Mobile Communication), which comprises a multiplicity of mobile switching centers MSC which are networked with one another and/or provide access to a fixed network PSTN/ISDN. Furthermore, these mobile switching centers MSC are connected to in each case at least one base station controller BSC, which can also be formed by a data processing system. A similar architecture is also to be found in a UMTS (Universal Mobile Telecommunication System).

Each base station controller BSC is connected, in turn, to at least one base station BS. Such a base station BS is a radio station which can use an air interface to set up a radio link to other radio stations, what are termed mobile stations MS. Information inside radio

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channels f which are situated inside frequency bands b
can be transmitted by means of radio signals between
the mobile stations MS and the base station BS assigned
to these mobile

stations MS. The range of the radio signals of a base station substantially defines a radio cell FZ.

Base stations BS and a base station controller˘ BSC can
5   be combined to form a base station system BSS. The base station system BSS is also responsible in this case for radio channel management and/or assignment, data rate matching, monitoring the radiotransmission link, hand-over procedures and, in the case of a CDMA system,
10   assigning the spread code set to be used, and transfers the signaling information required for this purpose to the mobile stations MS.

For FDD (Frequency-Division Duplex) systems such as the
15   GSM, it is possible in the case of a duplex system to provide for the uplink u (mobile station (transmitting unit) to the base station (receiving unit)) frequency bands differing from those for the downlink d (base station (transmitting unit) to the mobile station
20   (receiving unit)). A plurality of frequency channels f can be implemented within the different frequency bands b by means of an FDMA (Frequency-Division Multiple Access) method.

25   Within the scope of the present application, the transmission unit is also understood as a communication unit, transmitting unit, receiving unit, communication terminal, radio station, mobile station or base station. Terms and examples used within the scope of
30   this application frequently refer also to a GSM mobile radio system; however, they are not in any way limited thereto, but can easily be mapped by a person skilled in the art with the aid of the description onto other, possibly future, mobile radio systems such as CDMA
35   systems, in particular wide-band CDMA systems.

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Data can be efficiently transmitted, separated and assigned to one or more specific connections and/or to the appropriate subscriber via an air interface by means of multiple access methods. It is possible to
5   make use for this purpose of time-division multiple access TDMA, frequency-division multiple access FDMA, code-

division multiple access CDMA or a combination of a plurality of these multiple access methods.

In FDMA, the frequency band b is broken down into a plurality of frequency channels f; these frequency channels are split up into time slots ts by means of time division multiple access TDMA. The signals transmitted within a time slot ts and a frequency channel f can be separated by means of spread codes, what is termed CDMA codes cc, that are modulated in a link-specific fashion onto the data.

The physical channels thus produced are assigned to logic channels according to a fixed scheme. The logic channels are physically distinguished into two types: signaling channels (or control channels) for transmitting signaling information (or control information) and, traffic channels (TCH) for transmitting useful data.
The signaling channels are further subdivided into:
- broadcast channels
- common channels
- dedicated/access control channels DCCH/ACCH

The group of broadcast channels includes the broadcast control channel BCCH, to which the MS receives radio information from the base station system BSS, the frequency correction channel FCCH and the synchronization channel SCH. The common control channels include the random access channel RACH. The bursts or signal sequences that are transmitted to implement these logic channels can include in this case for different purposes signal sequences K(i), what are termed correlation sequences, or signal sequences K(i) can be transmitted on these logic channels for different purposes.

A method for synchronizing a mobile station MS with a base station BS is explained below by way of example: during a first step of the initial search for a base station or search for a cell (initial cell search

procedure), the mobile station uses the primary
synchronization channel (SCH (PSC)) in order to achieve
a time slot synchronization with the strongest base
station. This can be ensured by means of a matched
filter or an appropriate circuit which is matched to
the primary synchronization code cp that is emitted by
all the base stations. In this case, all the base
stations BS emit the same primary synchronization code
cp of length 256.

The mobile station uses correlation to determine from a
received sequence the received signal sequences K(i),
using a principle which is explained in figures 6 to 11
and the associated description. In this case, peaks are
output by the output of a matched filter for each
received signal sequence of each base station located
within the reception area of the mobile station. The
detection of the position of the strongest peak permits
the determination of the timing of the strongest base
station modulo of the slot length. In order to ensure a
greater reliability, the output of the matched filter
can be accumulated over the number of time slots in the
non-coherent fashion. The mobile station therefore
carries out a correlation over a signal sequence of
length 256 chips as a matched-filter operation.

The synchronization code cp is formed in this case in
accordance with a signal sequence K(i) using a
principle as explained in figure 5 and the associated
description, or can be formed in such a way or can be
obtained in such a way. The signal sequence K(i) or the
synchronization code cp of length 256 is formed in this
case from two partial signal sequences K1(j), K2(k), of
length 16 in each case, or can be formed in such a way.

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These partial signal sequences form a partial signal
sequence pair (K1(j); K2(k)) in this case.

A signal sequence K(i) obtainable in such a way can
5 also be termed in this case a "hierarchical signal
sequence" or "hierarchical correlation

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sequence". A partial signal sequence can also be termed a "short correlation sequence" or "constituent sequence".

5   In this case, at least one partial signal sequence is a Golay sequence, also termed a Golay complementary sequence of length nx, denoted *here by $X=X_{NX}(k)$*. X can be formed using the following relationship:

$$X_0(k) = \delta(k)$$
$$X'_0(k) = \delta(k)$$
10
$$X_n(k) = X_{n-1}(k) + W_n \cdot X'_{n-1}(k - D_n)$$
$$X'_n(k) = X_{n-1}(k) - W_n \cdot X'_{n-1}(k - D_n),$$

$$k = 0, 1, 2, \ldots, 2^{NX}-1$$
$$n = 1, 2, \ldots, NX$$
$$D_n = 2^{P_n}$$

15

where

$$nx = 2^{NX}$$

$\delta(k)$ Kronecker delta function

P_n, n = 1, 2, ...NX; arbitrary permutation of the
20   numbers $\{0, 1, 2, \ldots, NX-1\}$,

W_n weights for the partial signal sequence
$(+1, -1, +i$ or $-i)$.

A method of Golay and Sivaswamy for generating Golay
25   sequences as such is also known from "Efficient Pulse compressor for Golay Complementary Sequences", Electronic Letters Vol. 27, No. 3, pp. 219.

W_n can therefore assume the values +1, -1, +i or -i,
30   or, in particular, assume the values +1 or -1 for the purpose of generating binary Golay sequences.

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Within the scope of the present application, W_n is also denoted as a unit variable. The set of the variables

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D_n, used for a Golay sequence, which can be calculated from the permutation P_n, is also denoted as delay matrix; the set of the selected weights W_n is also denoted as a weight matrix.

5

For example, W = [1,-1,1,1] can be selected for the unit variable and/or the weights of the weight matrix, which means that $W_1 = 1$; $W_2 = -1$; $W_3 = 1$; $W_4 = 1$ and for the delay matrix D = [8,4,1,2], which means that

10    $D_1=8=2^3=2^{P1}$; $D_2=4=2^2=2^{P2}$; $D_3=1=2^0=2^{P3}$; $D_4=2=2^1=2^{P4}$. The permutation or permutation matrix P=[3;2;0;1] yields the partial signal sequence X_4 = (1 1 1 -1 -1 1 -1 -1 1 1 1 -1 1 -1 1 1). This sequence can be used as one of the partial signal sequences such as K1(j), for

15   example.

By contrast with an orthogonal gold code used in conventional methods, the autocorrelation function of a signal sequence K(i) formed by two partial signal

20   sequences generally has poorer autocorrelation properties. It has, for example, higher secondary maxima and a higher r.m.s. value of the secondary minima. Moreover, UMTS link level simulations show that when such signal sequences K(i) are used in PSC for

25   slot synchronization in the case of a frequency shift (frequency error) between the transmitter and receiver the synchronization error is generally higher by contrast with the use of an orthogonal gold code.

30   However, complicated simulation tools created specifically for this aim could be used to determine partial signal sequence pairs (K1(j);K2(k)) consisting of at least one Golay sequence, on the basis of which it is possible to form signal sequences K(i) which can

35   be reliably determined, in particular, for

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synchronization between the base station and mobile station even in the case of a relatively high frequency shift between the transmitter and receiver, and thus lead to a small synchronization error. In this case, a
5   frequency shift of 10 kHz was also the starting point in the simulations

for the UMTS system. The use of a signal sequence K(i) or synchronization code cp that is or can be formed in such a way substantially reduces the outlay on calculating the correlation sums, that is to say on determining the signal sequence K(i) in the receiving mobile station MS for the purpose of synchronization, without the need to accept a simultaneous increase in the synchronization error. Moreover, it is also possible to dispense with the use of expensive crystals in the receiver for the purpose of frequency stabilization.

The calculation of the autocorrelation function as a function of the frequency error proved to be particularly suitable in the case of the simulations for the purpose of assessing the synchronization properties of a signal sequence K(i) formed by a permutation-unit variable pair.

The calculation of the autocorrelation function taking account of a frequency shift between the transmitting and receiving units can also be carried out in this case in accordance with the following formula:

$$a(\kappa)=ABS\left(\sum_{i=0}^{n-1-\kappa} K(i)\bullet[K(i+\kappa)\bullet exp(j\bullet 2\pi\bullet f_d\bullet i\bullet t_a))]\right)^*$$

κ shift

n   length of the sequence

i   index

f_d frequency shift

t_a sampling interval

[]*   denotes the complex conjugate

In this case, the values $a(\kappa)$ can be calculated for

$\kappa=0..n-1$. If the result is a plurality of partial signal sequence pairs which lead to an equally good ratio of principal maximum to the maximum secondary maximum in the autocorrelation function of the

5   resulting signal sequence K(i), the partial signal

sequence pairs which lead to a lower r.m.s. value of the secondary maxima can be selected in what follows. In this case, the ratio of the principal maximum to the maximum secondary maximum is to be as large as possible, and the r.m.s. value of the secondary minima is to be as small as possible. By using subsequent link level simulations on the UMTS system, for example, it is possible to determine partial signal sequence pairs which in the case of frequency errors of 0 kHz and 5 KHz and 10 kHz surprisingly behave with regard to the synchronization error as effectively as a conventional orthogonal gold code, which is not hierarchically designed and is known to have very good properties for synchronization.

In addition to the autocorrelation function, the following criteria can also be used to select partial signal sequence pairs $(K1(j);K2(k))$:

-    Missed detection rate: select the partial signal sequence pairs by comparing the missed detection rate when carrying out complete simulations.

-    Detection probabilities for a given frequency error and a given SNR in the case of AWGN channels.

It was possible using the complicated simulations to determine a set of Golay sequences of length 16, described by a set of permutation/unit variable pairs which is specified in one and/or more of claims 1, 2, 3 or 4 on the basis of which it is possible to form signal sequences $K(i)$ which have a small synchronization error both for a frequency shift of zero between the transmitter and receiver and for a larger frequency shift in the case of use for

synchronization purposes. This leads to a preferred selection of permutation/unit variable pairs from which partial signal sequences and, finally, signal sequences K(i) can be obtained or formed.

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In one variant design of the invention, at least one partial signal sequence is a Golay sequence in particular of length 16, optimized with regard to the secondary maxima of the autocorrelation function even in the case of frequency errors.

It turned out to be advantageous in the case of the simulations explained above, to use a signal sequence $K(i)$ based on a partial signal sequence, the permutation P_1, P_2, P_3, P_4 and complex unit variable W_1, W_2, W_3, W_4 used to form the partial signal sequence being taken from the following set of permutation/unit variable pairs (P_1, P_2, P_3, P_4 , W_1, W_2, W_3, W_4;):

```
0213,+j+j+j-1; 0213,-j+j+j-1; 0213,+1-j+j-1; 0213,-1-j+j-1;
0213,+1+j-j-1; 0213,-1+j-j-1; 0213,+j-j-j-1; 0213,-j-j-j-1;
0213,+j+j+j+1; 0213,-j+j+j+1; 0213,+1-j+j+1; 0213,-1-j+j+1;
0213,+1+j-j+1; 0213,-1+j-j+1; 0213,+1-j-j+1; 0213,-j-j-j+1;
3120,+1-j+j-1; 3120,-1-j+j-1; 3120,+1+j-j-1; 3120,-1+j-j-1;
3120,+1+j+j+j; 3120,-1-j+j+j; 3120,+1-j-j+j; 3120,-1-j-j+j;
3120,+1+j+j-j; 3120,-1+j+j-j; 3120,+1-j-j-j; 3120,-1-j-j-j;
3120,+1-j+j+1; 3120,-1-j+j+1; 3120,+1+j-j+1; 3120,-1+j-j+1;
```

It proved to be particularly advantageous in the case of the simulations explained above to use a signal sequence $K(i)$ based on a partial signal sequence, the permutation P_1, P_2, P_3, P_4 and binary unit variable W_1, W_2, W_3, W_4 used to form the partial signal sequence being taken from the following set of permutation/unit variable pairs (P_1, P_2, P_3, P_4, W_1, W_2, W_3, W_4):

```
3201, +1-1+1+1; 3201, -1-1+1+1; 3201, +1-1-1+1; 3201,
-1-1-1+1; 3201, +1-1+1-1; 3201, -1-1+1-1; 3201, +1-1-
1-1; 3201, -1-1-1-1; 1023, +1+1-1+1; 1023, -1+1-1+1;
1023, +1-1-1+1; 1023, -1-1-1+1; 1023, +1+1-1-1; 1023,
```

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-1+1-1-1; 1023, +1-1-1-1; 1023, -1-1-1-1;.

It proved to be particularly advantageous in the case of the simulations explained above to use a signal sequence K(i) based on a partial signal sequence, the permutation P_1, P_2, P_3, P_4 and binary unit variable W_1, W_2, W_3, W_4 used to form the partial signal sequence being taken from the following set of permutation/unit variable pairs (P_1, P_2, P_3, P_4, W_1, W_2, W_3, W_4):

3201, +1-1+1+1; 3201, -1-1-1+1; 3201, -1-1+1-1; 3201, +1-1-1-1; and the permutation (P_1, P_2, P_3, P_4) used to form the second partial signal sequence is equal to 3201.

As already explained above - in addition to the permutation/unit variable representation, it is also possible to represent the Golay sequences by specifying the delay matrix and the weight matrix. The sequence with real weights which is specified as particularly advantageous in the first place above, the sequence (3201,+1-1+1+1) specified by the parameters (P_1, P_2, P_3, P_4, W_1, W_2, W_3, W_4) is therefore defined by the delay matrix D = [8, 4, 1,2] and the weight matrix W = [1, -1, 1,1].

Furthermore, the Golay sequence can also be represented explicitly by specifying the individual elements, the result for the above-named Golay sequence of length 16 being in this case:
K1= <+1,+1,+1,-1,-1,+1,-1,-1,+1,+1,+1,-1,+1,-1,+1,+1>
A further equivalent representation follows in the case of the mapping from +1 to 0 and -1 to 1 that is frequently used in the literature. The sequence is then defined by:
<0,0,0,1,1,0,1,1,0,0,0,1,0,1,0,0>

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Thus, if Golay sequences of length 16 are used as partial signal sequences (constituent sequences) for the PSC of UMTS, $W_n=1,-1$, i -i being permitted as weights, an arbitrary permutation from $D_n=\{1,2,4,8\}$

5   being permitted as delays,

the result is more than 2_{12} different possibilities for each of the two constituent sequences, that is to say a total of 2_{24} possibilities. In accordance with patent claims 1, 2, 3, or 4 the scope of the invention includes approximately 10 to $10^{\wedge}2$ permutation/unit variable pairs. The selected permutation/unit variable pairs therefore form only a very small subset of the fundamentally possible set of permutation/unit variable pairs that can be used to form 16-digit Golay sequences.

Figure 2 shows a radio station which can be a mobile station MS, consisting of an operating unit or interface unit MI, a control device STE, a processing device VE, a power supply device SVE, a receiving device EE and, if appropriate, a transmitting device SE.

The control device STE essentially comprises a program-controlled microcontroller MC, which can access memory chips SPE by writing and reading. The microcontroller MC controls and monitors all essential elements and functions of the radio station.

The processing device VE can also be formed by a digital signal processor DSP, which can likewise access memory chips SPE. Addition and multiplication means can also be realized by means of the processing device VE.

The program data required for controlling the radio station and the communication cycle, as well as, in particular, the signaling procedures, and information produced during the processing of signals are stored in the volatile or nonvolatile memory chips SPE. Moreover, signal sequences K(i) which are used for correlation

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purposes, and intermediate results of correlation sum calculations can also be stored therein. The signal

sequences K(i) within the scope of the invention can thus be stored in the mobile station and/or the base station. It is also possible for one or more of the permutation/unit variable pairs set forth above or

5   partial signal sequences or partial signal sequence pairs (K1(j);K2(k)) derived therefrom to be stored in the mobile station and/or the base station. It is also possible for a signal sequence K(i) to be formed from a partial signal sequence pair (K1(j);K2(k)) and/or a

10   partial signal sequence to be formed from a permutation/unit variable pairs in the mobile station and/or the base station.

In particular, it is possible to store in a base

15   station or in all the base stations in a system a signal sequence K(i) which is emitted at fixed or variable intervals for synchronization purposes. The partial signal sequence pair (K1(j);K2(k)), from which the signal sequence K(i) stored in the base station can

20   be formed, is stored in the mobile station MS and is used to synchronize the mobile station with a base station in order to calculate the correlation sum favorably in terms of computation outlay.

25   The storage of the signal sequences or the partial signal sequences can also be performed by storing appropriate information in arbitrarily coded form, and can be implemented with the aid of means for storage such as, for example, volatile and/or nonvolatile

30   memory chips or by means of appropriately designed adder or multiplier inputs or appropriate hardware configurations which have the same effect.

The high-frequency section HF comprises, if

35   appropriate, the transmitting device SE, with a

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modulator and an amplifier V, and a receiving device EE
with a demodulator and, likewise, an amplifier. The
analog audio signals and the analog signals originating
from the receiving device EE are converted by means of
5   analog-to-digital conversion into digital signals and
processed by the digital signal processor DSP. After
processing,

the digital signals are converted, if appropriate, by digital-to-analog conversion into analog audio signals or other output signals and analog signals that are to be fed to the transmitting device SE. Modulation or demodulation, respectively, is carried out for this purpose, if appropriate.

The transmitting device SE and the receiving device EE are fed with the frequency of a voltage-controlled oscillator VCO via the synthesizer SYN. The system clock for timing processor devices of the radio station can also be generated by means of the voltage-controlled oscillator VCO.

An antenna device ANT is provided for receiving and for transmitting signals via the air interface of a mobile radio system. The signals are received and transmitted in what are termed bursts that are pulsed over time in the case of some known mobile radio systems such as the GSM (Global System for Mobile Communication).

The radio station may also be a base station BS. In this case, the loudspeaker element and the microphone element of the operating unit MMI are replaced by a link to a mobile radio network, for example via a base station controller BSC or a switching device MSC. The base station BS has an appropriate multiplicity of transmitting and receiving devices, respectively, in order to exchange data simultaneously with a plurality of mobile stations MS.

The received signal sequence E(l), which can also be a signal sequence derived from a received signal, of length w is illustrated in figure 3. In order to calculate a first correlation sum S0 in accordance with

the formula specified at the beginning, elements of a
first section of this received signal sequence E(1) are
multiplied in pairs by the corresponding elements of
the signal sequence K(i) of length n, and the length of
5   the resulting partial results is added to the
correlation sum S0.

In order to calculate a further correlation sum S1, as illustrated in the figure, the signal sequence K(i) is shifted to the right by one element, and the elements of the signal sequence K(i) are multiplied in pairs by
5   the corresponding elements of the signal sequence E(1), and the correlation sum S1 is formed again by summing the partial results produced.

The pairwise multiplication of the elements of the
10 signal sequence by corresponding elements of the received signal sequence, and the subsequent summation can also be described in vector notation as the formation of a scalar product, if the elements of the signal sequence and the elements of the received signal
15 sequence are respectively aligned to form a vector of a Cartesian coordinate system:

$$S0 = \begin{pmatrix} K(0) \\ \vdots \\ K(i) \\ \cdot \\ K(n-1) \end{pmatrix} * \begin{pmatrix} E(0) \\ \vdots \\ E(i) \\ \vdots \\ E(n-1) \end{pmatrix} = K(0)*E(0)+..+K(i)*E(i)+...+K(n-1)*E(n-1)$$

$$S1 = \begin{pmatrix} K(0) \\ \vdots \\ K(i) \\ \vdots \\ K(n-1) \end{pmatrix} * \begin{pmatrix} E(1) \\ \vdots \\ E(i+1) \\ \vdots \\ E(n) \end{pmatrix} = K(0)*E(1)+...+K(i)*E(i+1)+...+K(n-1)*E(n)$$

20
In the correlation sums S thus determined, it is possible to search for the maximum and compare the maximum of the correlation sums S with a prescribed threshold value and thus determine whether the
25 prescribed signal sequence K(i) is included in the

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received signal E(l) and if so where it is located in
the received signal E(l) and thus two radio stations
are synchronized with one another or data are detected
on to which

an individual spread code has been modulated in the
form of a signal sequence K(i).

Represented again in figure 4 is the received signal
5   sequence E(l) and, as correlation sequence a signal
sequence K(i) which is based on the partial signal
sequences K1(j), K2(k).

Represented in figure 5 is the formation of a signal
10   sequence K(i) which is based on two partial signal
sequences K2(k) of length n2 and K1(j) of length n1.
For this purpose, the partial signal sequence K2(k) is
repeated n1 times and modulated in the process by the
partial signal sequence K1(k). The formation of the
15   signal   sequence   K(i)   can   also   be   expressed
mathematically by the following formula:

$$K(i) = K2(i \bmod n2) * K1(i \operatorname{div} n2), \text{ for } i = 0 \ldots n1*n2-1$$

20

mod denotes the integral remainder of a division, and
div denotes the integral result of a division.

This is illustrated by a sequence f2 which consists of
25   the   repeated,   sequentially   mapped   partial   signal
sequences K2(k), and a sequence f1 which is mapped by
an extended partial signal sequence K1(j) over the
sequence f2.

30   The new signal sequence K(i) of length n is produced by
multiplying the elements of the sequence f2 by the
corresponding elements, mapped over the sequence f2, of
the sequence f1. This generation of a signal sequence
K(i) is represented once again at the bottom of the
35   illustration with the aid of an example of two binary

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partial signal sequences of length 4.

The invention is not, of course, limited to partial
signal sequences of length 4 or signal sequences of

5   length 16. Neither is the invention limited to the
mathematical description used above.

For example, the following representation for partial
signal sequences of length 16 or signal sequences of
length 256 correspond in content to the mathematical
representation used above, and is therefore likewise
5   contained in the invention:

For example, if use is made for K1 of the Golay
sequence, described above as particularly favorable,
with the permutation/unit variable representation
10 (3201 , +1-1+1+1) or the explicit representation
<+1,+1,+1,-1,-1,+1,-1,-1,+1,+1,+1,-1,+1-1,+1,+1>, and
for K2 of a sequence a consisting of 16 elements, it is
also possible to write the repeated, sequentially
mapped partial signal sequences K2 and a, which are
15 modulated with the value of the respective element of
the sequence K1, as follows:

K = <a, a, a, -a, -a, a, -a, -a, a, a, a, -a, a, -a, a,
a>
20

Signal sequences K(i) formed in such a way can be used
for simplified calculation of correlation sums of these
signal sequences K(i) with received signal sequences
E(1)._The signal sequence of length 256 thus formed
25 can, for example, be emitted for synchronization
purposes as primary synchronization code cp of length
256.

A schematic of such a simplified calculation of
30 correlation sums S, which is therefore also faster and
more favorable in terms of outlay, is represented in
figures 6 to 8, which are examined below.

The first step is to form a partial correlation sum
35 TS(z). For this purpose, for example, the correlation

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sum of the second partial signal sequence K2(k) with the corresponding section of the received signal sequence E(l) is formed for the first element of the partial correlation sequence TS(0).

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$$TS(0) = \begin{pmatrix} K2(0) \\ \cdot \\ K2(k) \\ \cdot \\ K2(n2-1) \end{pmatrix} * \begin{pmatrix} E(0) \\ \cdot \\ E(k) \\ \cdot \\ E(n2-1) \end{pmatrix} = K2(0)*E(0)+...+K2(k)*E(k)+...+K2(n2-1)*E(n2-1)$$

As illustrated, for the second element of the partial correlation sum sequence TS(1) the second partial signal sequence K2(k) is shifted by one element, and the correlation sum with the corresponding element of the received signal sequence E(1) is likewise formed, etc.

$$TS(1) = \begin{pmatrix} K2(0) \\ \cdot \\ K2(k) \\ \cdot \\ K2(n2-1) \end{pmatrix} * \begin{pmatrix} E(1) \\ E(k+1) \\ \vdots \\ E(n2) \end{pmatrix} = K2(0)*E(1)+ . +K2(k)*E(k+1)+ ..+K2(n2-1)*E(n2)$$

The n-th element of the partial correlation sum sequence TS(n1*n2-1) is calculated correspondingly after n-1 shifts of the second partial signal sequence K2(k) with respect to the received signal sequence E(1).

$$TS(n-1) = \begin{pmatrix} K2(0) \\ \vdots \\ K2(k) \\ \vdots \\ K2(n2-1) \end{pmatrix} * \begin{pmatrix} E(n-1) \\ \vdots \\ E(k+n-1) \\ \vdots \\ E(n2+n-2) \end{pmatrix} =$$

$$= K2(0)*E(n-1)+...+K2(k)*E(k+n-1)+...+K2(n2-1)*E(n2+n-2)$$

The partial correlation sum sequence TS(z) thus produced is represented at the top in figure 7. Each n2-th element is now selected from this partial

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correlation sum sequence and multiplied by the corresponding element of the first partial signal sequence K1(j) in pairs.

Combining the selected elements of the partial correlation sum sequence TS(z) and the first partial signal sequence K1(k) to form vectors in each case produces the first correlation sum S0 by means of the scalar product of these two vectors.

$$S0 = \begin{pmatrix} K1(0) \\ \vdots \\ K1(j) \\ \vdots \\ K1(n1-1) \end{pmatrix} * \begin{pmatrix} TS(0) \\ \vdots \\ TS(j*n2-1) \\ \vdots \\ TS((n1-1)*n2-1) \end{pmatrix} = K1(0)*TS(0)+...+K1(j)*TS(j*n2-1)+...$$

Figure 7 shows at the bottom the corresponding calculation of further correlation sums S1 and S2, respectively, through the selection of n2-th elements situated one or two to the right of the initially selected elements:

$$S1 = \begin{pmatrix} K1(0) \\ \vdots \\ K1(j) \\ \vdots \\ K1(n1-1) \end{pmatrix} * \begin{pmatrix} TS(1) \\ \vdots \\ TS(j*n2) \\ \vdots \\ TS((n1-1)*n2) \end{pmatrix} = K1(0)*TS(0)+...+K1(j)*TS(j*n2)+...$$

By storing partial correlation sums TS once calculated, it is possible to have recourse to them again when later calculating further correlation sums, and thus to dispense with the corresponding computational steps.

Depending on the design variant, it is possible either firstly to calculate the complete partial correlation sum sequence TS(z) over the entire received signal sequence E(1), and then to calculate the individual correlation sums, or not to calculate the corresponding additionally required partial correlation sums until

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required for the purpose of calculating a new
correlation sum.

Figure 8 shows, once again, the method consisting of
two steps, for calculating correlation sums S, this
time with the aid of the example, represented in
figure 5, of two binary partial signal sequences of
length 4.

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In a first step, the partial correlation sums TS(z) of the second partial signal sequence K2(k) +-++ are calculated with corresponding sections of the received signal sequence E(1) and, in a second step, each fourth element of the partial correlation sum sequence TS(z) thus produced is then selected, multiplied by the corresponding element of the first partial signal sequence K1(j) +++-, and summed to form the correlation sequence S0.

The bold lines in this case represent the calculation steps that have to be carried out anew for calculation of a further correlation sum S1 for the case in which the remaining partial correlation sums TS have already previously been calculated and stored.

This variant design can be carried out as efficiently as possible in terms of storage if each n2-th partial correlation sum is firstly calculated. The samples are buffered for this purpose.

Figures 9 to 10 present another variant design for simplified calculation of correlation sums S with the aid of the example, already mentioned above, of two binary partial signal sequences of length 4.

The first step here is to select each 4th element of the received signal sequence E(1) and to form the partial correlation sum sequence TS(z) of the elements thus selected with the partial signal sequence K1(k). Four sequential elements are respectively selected from the partial correlation sum sequence TS(z) thus produced and multiplied in pairs by corresponding elements of the partial signal sequence K2(k), and the resulting partial results are summed to form the

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correlation sum S. Once again, here, the bold lines represent the additionally required steps for calculating a further correlation sum S1 for the case in which the other partial correlation sums TS have already been calculated and stored before.

Figure 10 shows, once again, the calculation of a first correlation sum S0, in the case of which firstly each 4th element of the received signal sequence E(1) is selected, these elements are multiplied by corresponding elements of the first partial signal sequence K1(k) +++-, and the partial correlation sum TS(0) is calculated by summing the partial results. In a second step the first 4 sequential elements of the partial correlation sum sequence TS(z) are multiplied by the corresponding elements of the second partial signal sequence K2(k) +-++, and the partial results produced are summed to form the correlation sum S0.

This variant design requires less storage for buffering the partial correlation sums when the sums are calculated successively.

A further refinement of the invention utilizes the regular (fast periodic) structure, caused by the regular design principle of the signal sequence K(i), of the aperiodic autocorrelation function of this signal sequence. This means that when a signal is being sought not only is a principal maximum produced, but secondary maxima also occur at regular intervals. The regularity of the position of the maxima can be utilized to accelerate the search for the signal sequence in the received signal sequence. As soon as a secondary maxima has been found, it is possible to predict the position of the other maxima on the basis of the periodicity. That is to say the correlation sum is calculated only at these points. The principal maximum can be detected quickly in this way. However, the supposed secondary maximum can also be only a randomly increased value (because of the noise component). In this case, no maximum will actually be

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found at the potential points of the expected principal maximum. Consequently, the hypothesis is rejected in this case and the calculation is continued conventionally.

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However, the regularity, caused by the design principle of the signal sequences, of the secondary maxima can also be utilized to eliminate and correct interfering secondary maxima in the correlation result. After the detection of the maximum, the secondary maxima can be calculated therefrom and this value can be subtracted from the corresponding correlation results. The correlation result of a (hypothetical) sequence with a perfect autocorrelation function is obtained in this way. This results in a greatly simplified calculation owing to the regularity of the secondary maxima.

In variant designs of the invention, efficient Golay correlators are used to calculate scalar products, correlation sums and/or partial correlation sums.

Figure 11 shows an efficient hierarchical correlator for signal sequences, Golay sequences X,Y of length nx and ny respectively being used as constituent sequences K1, K2. The correlator consists of two series-connected matched filters (figure 11a) which are respectively formed as efficient Golay correlators. Figure 11b) shows the matched filter for the sequence X, and figure 11 c) shows the matched filter for the sequence Y.

The following designations apply in figure 11 b):

$n = 1, 2, \ldots NX$

ny   length of sequence Y

nx   length of sequence X

NX   with $nx = 2^{NX}$

DX_n $DX_n = 2^{PX_n}$

PX_n permutation of the numbers $\{0, 1, 2, \ldots, NX-1\}$ for the partial signal sequence X

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WX_n weights for the partial signal sequence X
from (+1,-1,+i or -i).

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The following designations apply in figure 11 c):

$n = 1, 2, \ldots NY$

ny   length of sequence Y

NY   with $ny=2^{NY}$

DY_n $DY_n = 2^{PY_n}$

PY_n permutation of the
numbers $\{0, 1, 2, \ldots, NY-1\}$
for the partial signal sequence Y

WY_n weights for the partial signal sequence Y
from (+1,-1,+i or -i)

Moreover, the following definitions and designations are valid in these variant designs:

$a_n(k)$ and $b_n(k)$ are two complex sequences of length 2^N,

$\delta(k)$ is the Kronecker delta function

k is an integer representing time,

n is the iteration number,

D_n is the delay,

P_n, $n = 1, 2, \ldots, N$, is an arbitrary permutation of the numbers $\{0, 1, 2, \ldots, N-1\}$,

W_n can assume the values +1, -1, +i, -i as weights and is also designated as unit variable.

The correlation of a Golay sequence of length 2^N can now be carried out efficiently as follows:
The sequences $R_a(0)(k)$ and $R_b(0)(k)$ are defined as $R_a(0)(k) = R_b(0)(k) = r(k)$, $r(k)$ being the received signal or the output of another correlation stage.

The following step is executed N times: n runs from 1 to N:

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Calculate

$$R_a^{(n)}(k) = W*_n * R_b^{(n-1)}(k) + R_a^{(n-1)}(k- D_n)$$

and

$$R_b^{(n)}(k) = W*_n * R_b^{(n-1)}(k) + R_a^{(n-1)}(k- D_n),$$

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$W^{*}{}_{n}$ designating the complex conjugate of W_{n}. If the weights W are real, $W^{*}{}_{n}$ is identical to W_{n}.

$R_{a}{}^{(N)}$ (k) is then the correlation sum to be calculated.

5 An efficient Golay correlator for a PSC code of length 256 (2^{8}) chips in the receiver generally has 2*·8-1=15 complex adders. With the combination of hierarchical correlation and efficient Golay correlator, a hierarchical code - described by two constituent

10 sequences X and Y - of length 256 ($2^{4} \cdot 2^{4}$) requires only 2·4-1+2·4-1 = 14 complex adders (even when use is made of four-valued constituent sequences). This reduces by 7% the outlay on calculation, which is very high for the primary synchronization in CDMA mobile radio

15 systems.

Specified below - marked in each case by dividing dashes - of variant designs of the invention the implementation of which are within the activity of a

20 person skilled in the art given knowledge of the present application:

-    to form a code sequence of length 2^{NX+NY}, two constituent Golay sequences of length $nx=2^{NX}$ and $ny=2^{NY}$

25 are used and are hierarchically constructed as described above.

-    +1 and -1 are used as weights for the constituent Golay sequences, binary sequences thereby being

30 produced.

-    +1, -1, i or -i are used as weights for the constituent Golay sequences, four-valued sequences thereby being produced.

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-     Real Golay sequences are used.

-     Complex Golay sequences are used.

-       Two constituent Golay sequences of equal length
are used.

-       Two complementary Golay sequences are used.

-       Only one efficient Golay correlator, with
programmable delays, if appropriate, is used for
optional calculation of one or both complementary Golay
sequences.

-       A sequence is used as described, but additional
values are also inserted; these values must be
accumulated as usual during the calculation. The
remainder of the calculation can, however, be carried
out efficiently as described. This permits the
generation of sequences of arbitrary length.

-       Two constituent sub-sequences are used.

-       A plurality of constituent sub-sequences are
used.

-       A Golay sequence is used only for some of the
sub-sequences.

-       These sequences are used for the synchronization
channel in UMTS.

-       Constituent Golay sequences optimized for
frequency error are used.

-       Two series-connected filters are used to
calculate the correlation, one being a matched filter
matched to the Golay sequence X, the other being a
matched filter matched to the Golay sequence Y with

spread delays $ny \cdot DX_n$.

- Two series-connected filters are used to calculate the correlation, one being a matched filter matched to the Golay sequence X, and the other being a matched filter matched to the Golay sequence Y with spread delays $ny \cdot DX_n$,

and the output signals of the filters being calculated in accordance with the efficient Golay correlator algorithm.

5   -   The efficient Golay correlation algorithm is used to calculate the partial correlation sums and the algorithm for the hierarchical correlation is used to determine the overall correlation.

10   The present invention is not limited to radio transmission systems, but can also be employed in the use of other transmission methods, for example, acoustic method (ultrasound) in particular, for the purposes of sonography, or optical methods, for example

15   infrared measurement using lidar principles. A further field of application is the investigation of changes in the spectral composition of backscattered signals.

Patent claims

1. A method for synchronizing a base station (BS)
    with a mobile station (MS),
    - in which there is emitted by the base station
    (BS) a signal sequence K(i) of length 256 which
    can be obtained by virtue of the fact that a
    second partial signal sequence K2(k) of length
    n2=16 is repeated n1=16 times and is modulated in
    the process with the first partial signal sequence
    K1(j) of length n1=16, the modulation of the
    second partial signal sequence K2(k) being
    performed using the following rule:
    K(i) = K2(i mod n2) * K1(i div n2), for i =0
    ...n1*n2-1,
    - at least one of the partial signal sequences
    being a Golay sequence $X_n(k)$ of length nx=n1=16,
    which can be formed using the following
    relationship:

$$X_0(k) = \delta(k)$$
$$X'_0(k) = \delta(k)$$
$$X_n(k) = X_{n-1}(k) + W_n \cdot X'_{n-1}(k - D_n)$$
$$X'_n(k) = X_{n-1}(k) - W_n \cdot X'_{n-1}(k - D_n),$$

$$k = 0, 1, 2, \ldots, 2^{NX-1}$$
$$n = 1, 2, \ldots, NX$$
$$D_n = 2^{P_n}$$

where
    nx=16=2^{NX}

    NX=4

    $\delta(k)$: Kronecker delta function,
    - the permutation P_1, P_2, P_3, P_4 and unit variable
    W_1, W_2, W_3, W_4 used to form a partial signal sequence
    being taken from the following set of

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permutation/unit variable pairs (P_1, P_2, P_3, P_4, W_1, W_2, W_3, W_4;):

3201, +1-1+1+1; 3201, -1-1+1+1; 3201, +1-1-1+1; 3201, -1-1-1+1; 3201, +1-1+1-1; 3201, -1-1+1-1; 3201, +1-1-1-1; 3201, -1-1-1-1; 1023, +1+1-1+1; 1023, -1+1-1+1; 1023, +1-1-1+1;

1023, -1-1-1+1; 1023, +1+1-1-1; 1023, -1+1-1-1; 1023,
+1-1-1-1; 1023, -1-1-1-1; .

2.   The method as claimed in claim 1, in which the
      signal sequence K(i) is formed using the following
      formation law by modulated repetition of a partial
      signal sequence a consisting of 16 elements:
      K = <a, a, a, -a, -a, a, -a, -a, a, a, a, -a, a, -a, a,
      a>

3.   The method as claimed in claim 1, in which the
      partial signal sequence K1(j) is a Golay sequence
      which is defined by the delay matrix D = [8,4,1,2]
      and the weight matrix W = [1,-1, 1,1].

4.   The method as claimed in claim 1, in which the
      permutation P_1, P_2, P_3, P_4 and unit variable W_1, W_2, W_3,
      W_4 used to form the first partial signal sequence
      is   taken   from   the   following   set   of
      permutation/unit variable pairs (P_1, P_2, P_3, P_4, W_1, W_2,
      W_3, W_4):
      3201, +1-1+1+1; 3201, -1-1-1+1; 3201, -1-1+1-1;
      3201, +1-1-1-1; and
      the permutation (P_1, P_2, P_3, P_4) used to form the
      second partial signal sequence is equal to 3201.

5.   The method as claimed in one of the preceding
      claims, in which the signal sequence K(i) is
      received by the mobile station (MS) as part of a
      received signal sequence E(l) and further
      processed for synchronization purposes.

6.   The method as claimed in one of the preceding
      claims, in which the signal sequence K(i) is
      determined by the mobile station (MS), knowledge

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of the first and second partial signal sequences K1(j) K2(k) being used in the mobile station.

7.   The method as claimed in one of the preceding claims,

- in which correlation sums S of the signal
sequence K(i) with corresponding sections of the
received signal sequence E(l) are determined in
the mobile station (MS),
- a partial correlation sum sequence TS(z) of the
partial signal sequence K2(k) with corresponding
parts of the received signal sequence E(l) being
calculated, and n1 elements of the partial
correlation sum sequence TS(z) being selected to
calculate a correlation sum S and being multiplied
by the partial signal sequence K1(j) to produce a
scalar product.

8.   The method as claimed in claim 7, in which n1 in
each case n2-th elements of the partial
correlation sum sequence TS(z) are selected to
calculate a correlation sum S.

9.   The method as claimed in one of claims 1 to 6,
- in which correlation sums S of the signal
sequence K(i) with corresponding sections of the
received signal sequence E(l) are determined in
the mobile station (MS),
- a partial correlation sum sequence TS(z) of the
partial signal sequence K2(k) with corresponding
elements of the received signal sequence E(l)
being calculated, and n2 elements of the partial
correlation sum sequence TS(z) being multiplied by
the partial signal sequence K2(k) to produce a
scalar product in order to calculate a correlation
sum S.

10. The method as claimed in claim 9, in which n1 in
each case n2-th elements of the received signal
sequence E(l) are selected to calculate a partial
correlation sum TS.

11.   The method as claimed in one of claims 7 to 11, in
       which calculated partial correlation sums TS are
       stored and used to calculate a further correlation
       sum S.

12. The method as claimed in one of the preceding claims, in which an efficient Golay correlator (EGC) is used in the mobile station (MS) in order at least partially to determine the signal sequence, in particular to calculate at least one correlation sum.

13. A method for synchronizing a base station (BS) with a mobile station (MS), in which
- the base station emits a synchronization sequence K of length 256 which can be formed as follows from a partial signal sequence a consisting of 16 elements:
K = <a, a, a, -a, -a, a, -a, -a, a, a, a, -a, a, -a, a, a> and
- a mobile station receives this synchronization sequence K and processes it for synchronization purposes.

14. A base station (BS)
- having means (SPE) for storing and/or for forming a signal sequence K(i) which can be obtained by virtue of the fact that a partial second signal sequence K2(k) of length n2=16 is repeated n1=16 times and is modulated in the process by the first partial signal sequence K1(j) of length n1=16, the modulation of the second partial signal sequence K2(k) being performed using the following rule:
k(i) = K2(i mod n2) * K1(i div n2), for i =0 ...n1*n2-1,
- at least one of the partial signal sequences being a Golay sequence $X_n(k)$ of length nx=n1=16 which can be formed using the following relationship:

$$X_0(k) = \delta(k)$$

$$X'_0(k) = \delta(k)$$

$$X_n(k) = X_{n-1}(k) + W_n \cdot X'_{n-1}(k - D_n)$$

$$X'_n(k) = X_{n-1}(k) - W_n \cdot X'_{n-1}(k - D_n),$$

$$k = 0, 1, 2, \ldots, 2^{NX}-1$$

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$$n = 1, 2, \ldots, NX$$

$$D_n = 2^{P_n}$$

where

nx=16=2^{NX}

NX=4

$\delta(k)$: Kronecker delta function,

- the permutation P_1, P_2, P_3, P_4 and unit variable W_1, W_2, W_3, W_4 used to form the partial signal sequence being taken from the following set of permutation/unit variable pairs (P_1 P_2 P_3 P_4, W_1 W_2 W_3 W_4;):

3201, +1-1+1+1; 3201, -1-1+1+1; 3201, +1-1-1+1; 3201, -1-1-1+1; 3201, +1-1+1-1; 3201, -1-1+1-1; 3201, +1-1-1-1; 3201, -1-1-1-1; 1023, +1+1-1+1; 1023, -1+1-1+1; 1023, +1-1-1+1; 1023, -1-1-1+1; 1023, +1+1-1-1; 1023, -1+1-1-1; 1023, +1-1-1-1; 1023, -1-1-1-1;, and

- with the means for emitting this signal sequence K(i) with the aim of synchronization with a receiving unit (MS).

15. A mobile station (MS)

- having means for determining a signal sequence K(i), which can be obtained by virtue of the fact that a second partial signal sequence K2(k) of length n2=16 is repeated n1=16 times and is modulated in the process with the first partial signal sequence K1(j) of length n1=16, the modulation of the second partial signal sequence K2(k) being performed using the following rule:

    K(i) = K2(i mod n2) * K1(i div n2), for i =0 ...n1*n2-1,

- at least one of the partial signal sequences being a Golay sequence $X_n(k)$ of length nx=n1=16, which can be formed using the following relationship:

- 36a -

$$X_0(k) = \delta(k)$$
$$X'_0(k) = \delta(k)$$
$$X_n(k) = X_{n-1}(k) + W_n \cdot X'_{n-1}(k - D_n)$$
$$X'_n(k) = X_{n-1}(k) - W_n \cdot X'_{n-1}(k - D_n),$$

- 37 -

$$k = 0, 1, 2, \ldots, 2^{NX}-1$$
$$n = 1, 2, \ldots, NX$$
$$D_n = 2^{P_n}$$

where

nx=16=2^{NX}

NX=4

δ (k): Kronecker delta function,

- the permutation P_1, P_2, P_3, P_4 and unit variable W_1, W_2, W_3, W_4 used to form a partial signal sequence being taken from the following set of permutation/unit variable pairs (P_1 P_2 P_3 P_4, W_1 W_2 W_3 W_4;):

3201, +1-1+1+1; 3201, -1-1+1+1; 3201, +1-1-1+1; 3201, -1-1-1+1; 3201, +1-1+1-1; 3201, -1-1+1-1; 3201, +1-1-1-1; 3201, -1-1-1-1; 1023, +1+1-1+1; 1023, -1+1-1+1; 1023, +1-1-1+1; 1023, -1-1-1+1; 1023, +1+1-1-1; 1023, -1+1-1-1; 1023, +1-1-1-1; 1023, -1-1-1-1;,

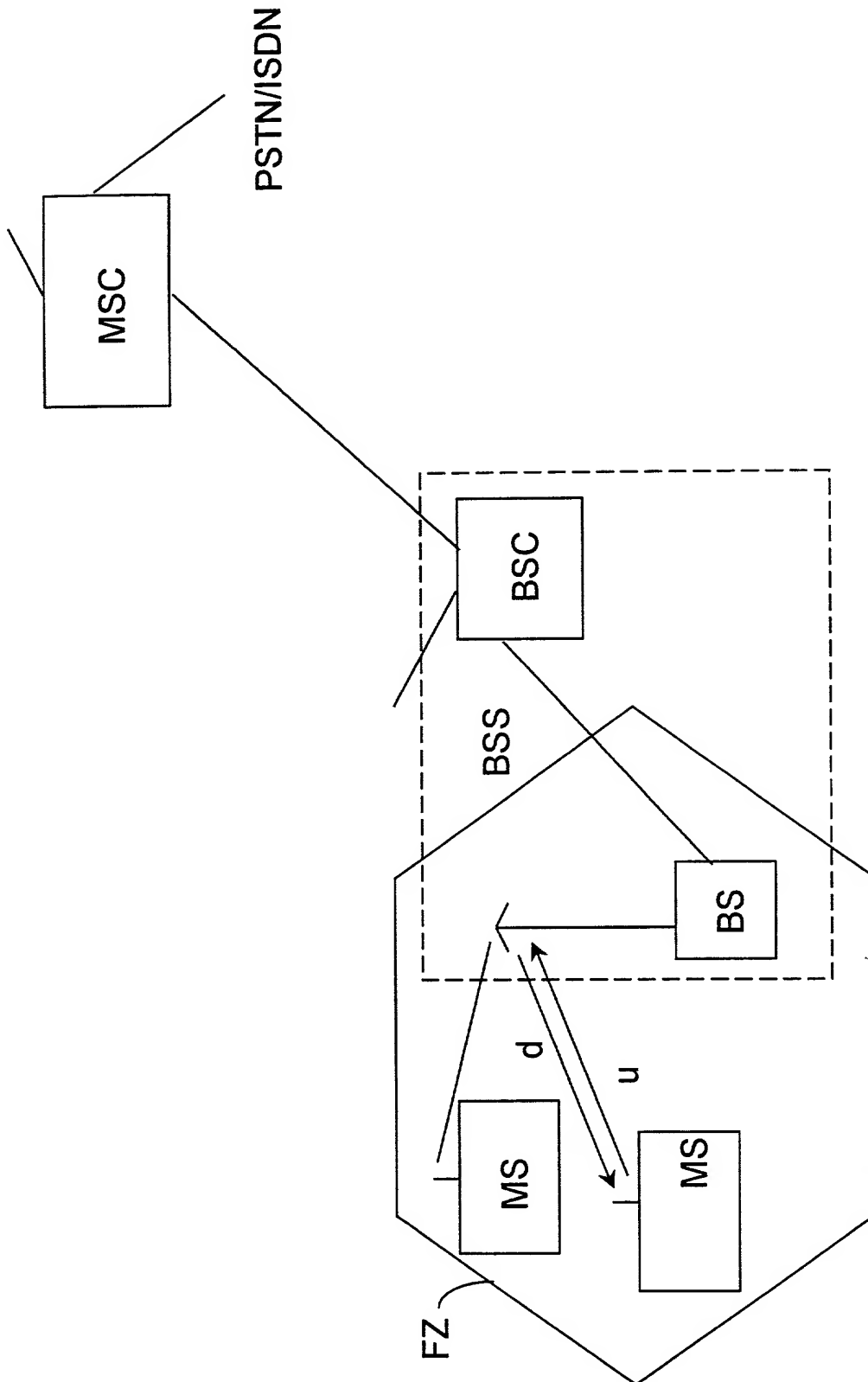and knowledge of the first and second partial signal sequences K1(j) K2(k) being used.
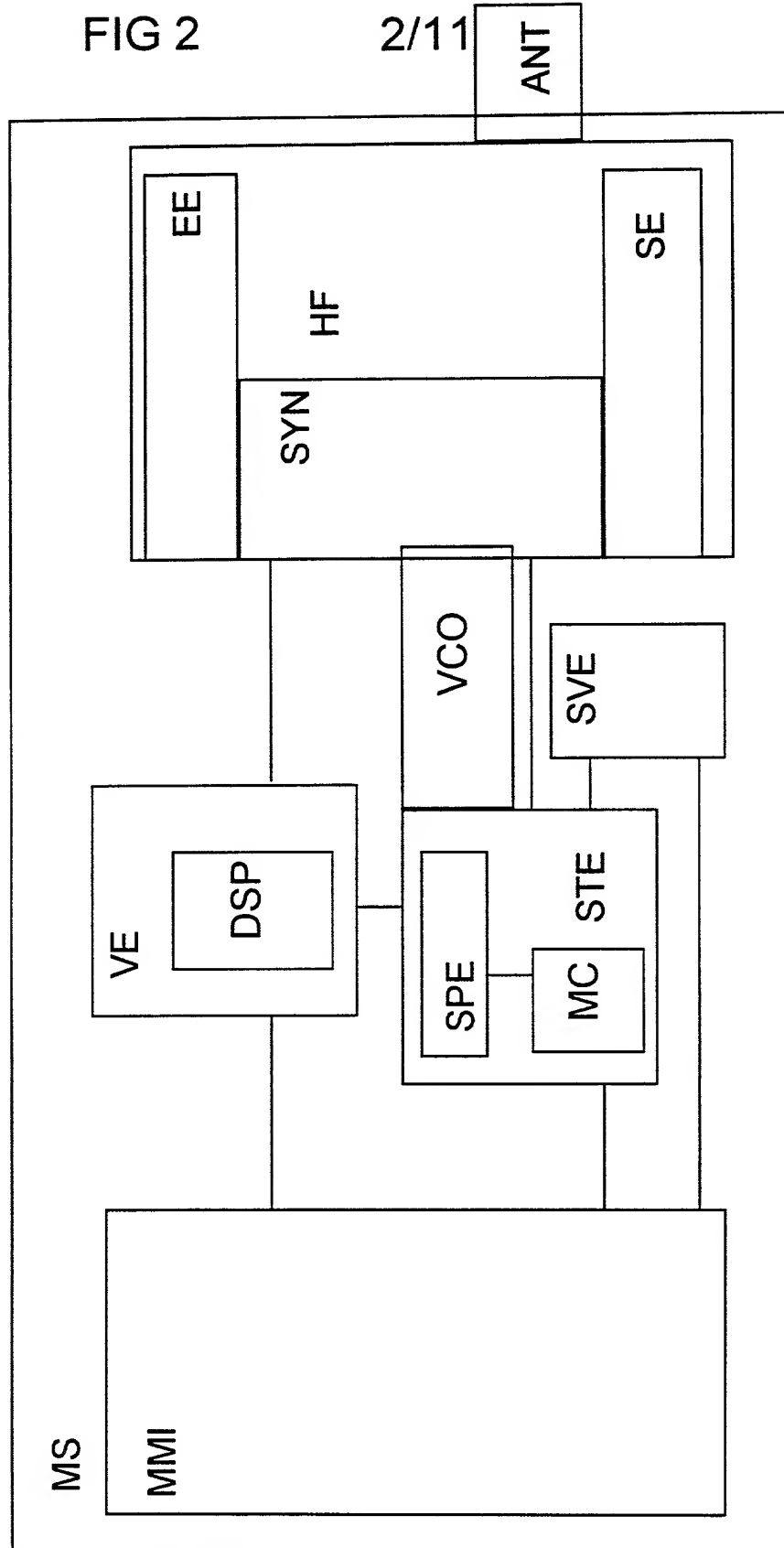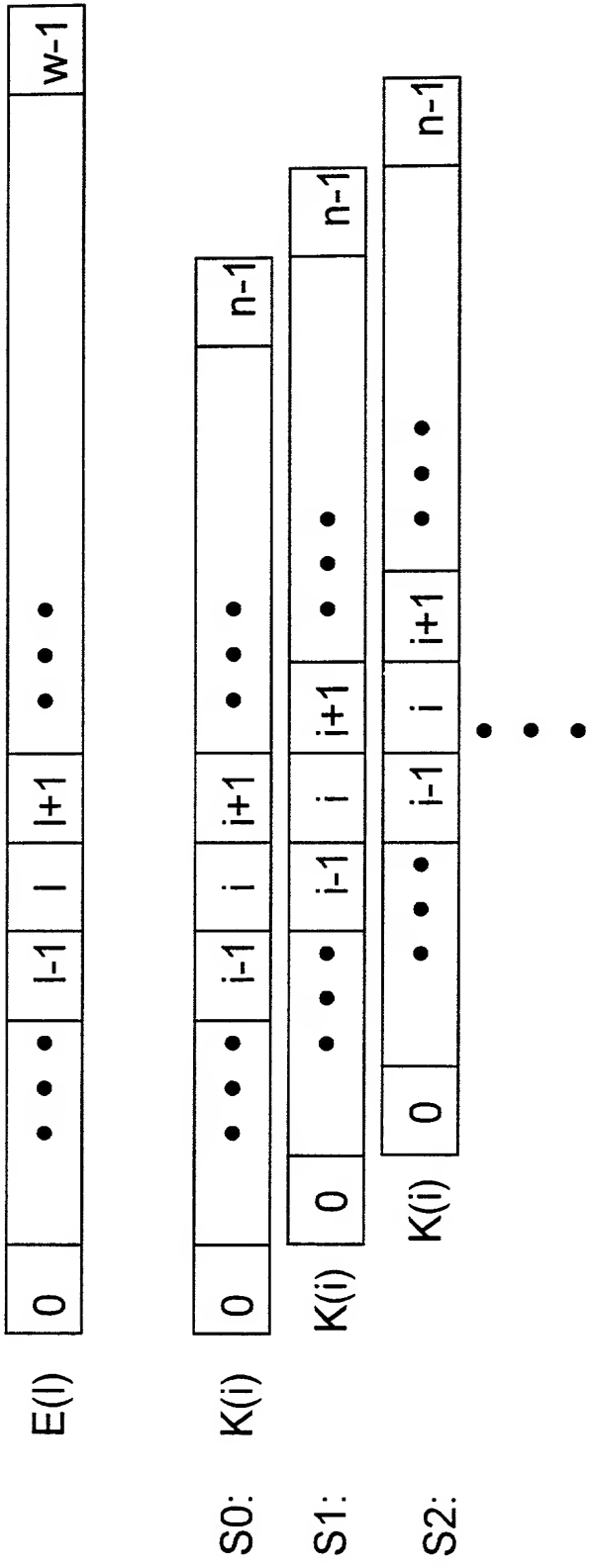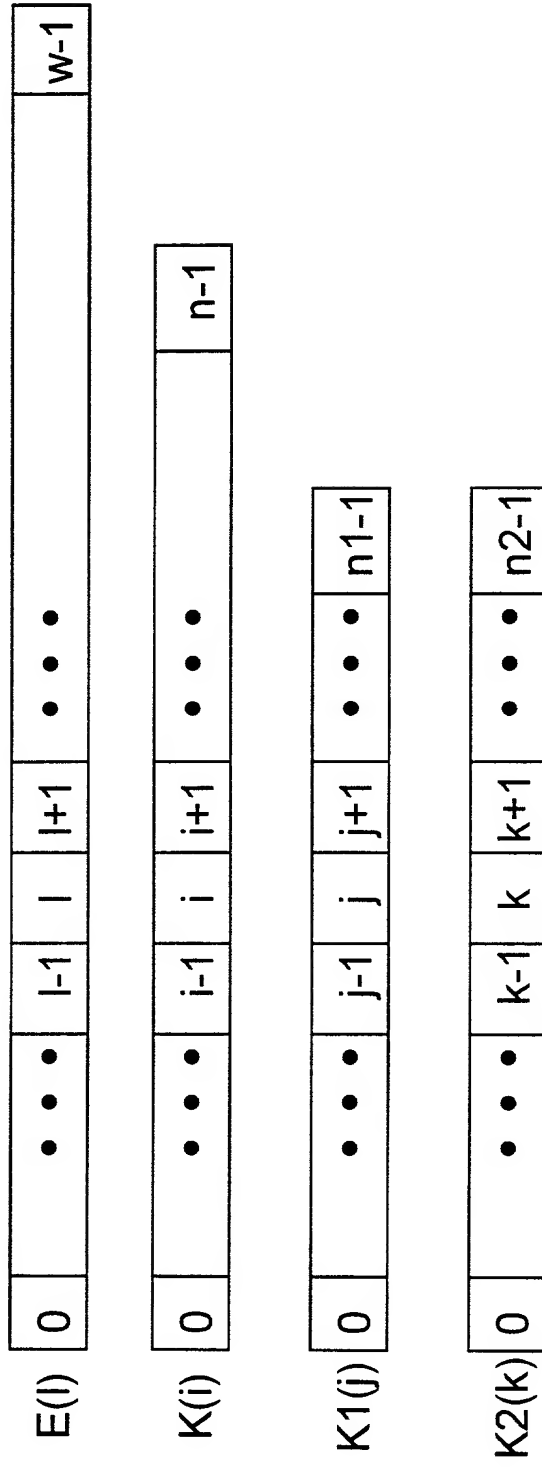
FIG 1   1/11

FIG 2 2/11

FIG 3   3/11

FIG 4 4/11

FIG 5

K1(j)

f1: | 0 | | | ••• | | k-1 | k | k+1 | ••• | n2-1 | | 1 | 0 | ••• | k-1 | k | k+1 | ••• | n2-1

K2(k)

K2(k)

K(i): | 0 | ••• | i-1 | i | i+1 | ••• | n-1

f1 | + | + | - | + | + | + | - | + | + | + | - | + | + | + | - |
f2 | + | - | + | - | + | + | - | + | + | + | - | + | + | - | - |

f1
f2

f1 * f2

FIG 6

E(l)

TS(0): K2(k)

TS(1): K2(k)

TS(n1*n2-1): K2(k)
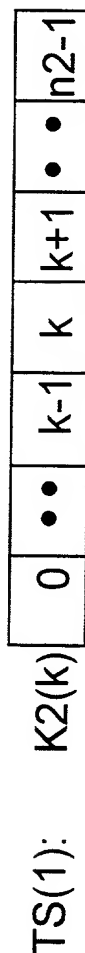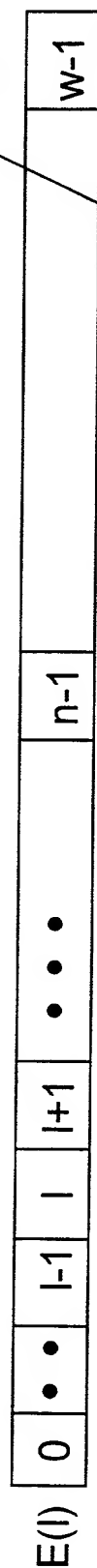
FIG 7   7/11

FIG 8   8/11

FIG 9   9/11
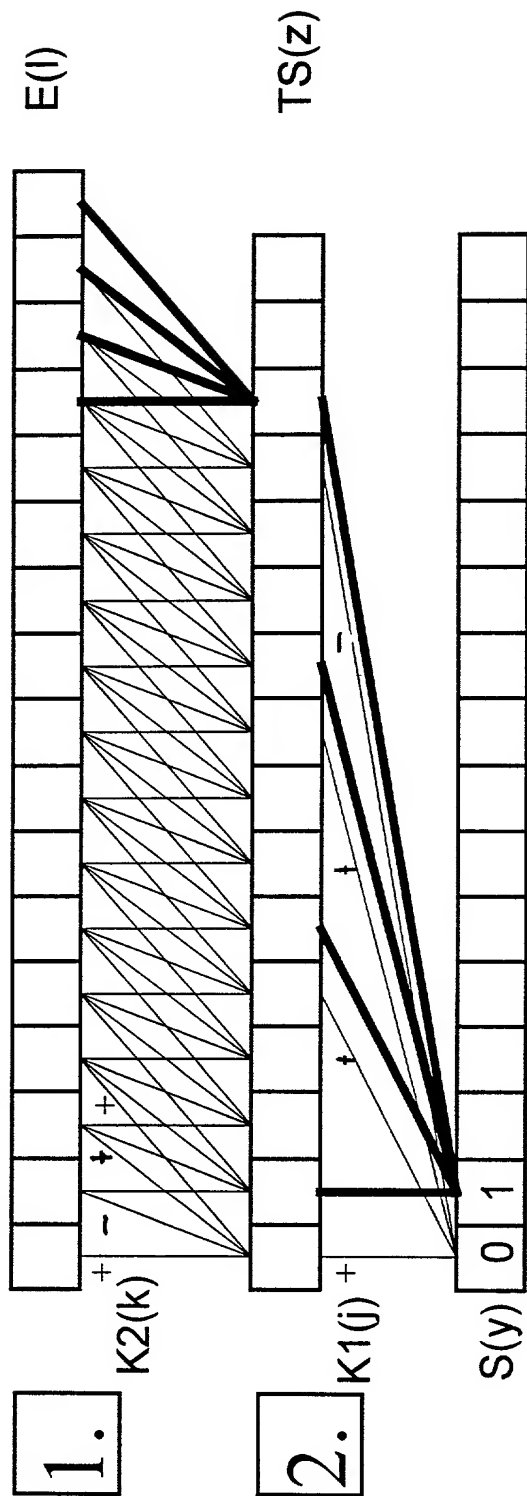

E(l)

K1(j)

TS(z):
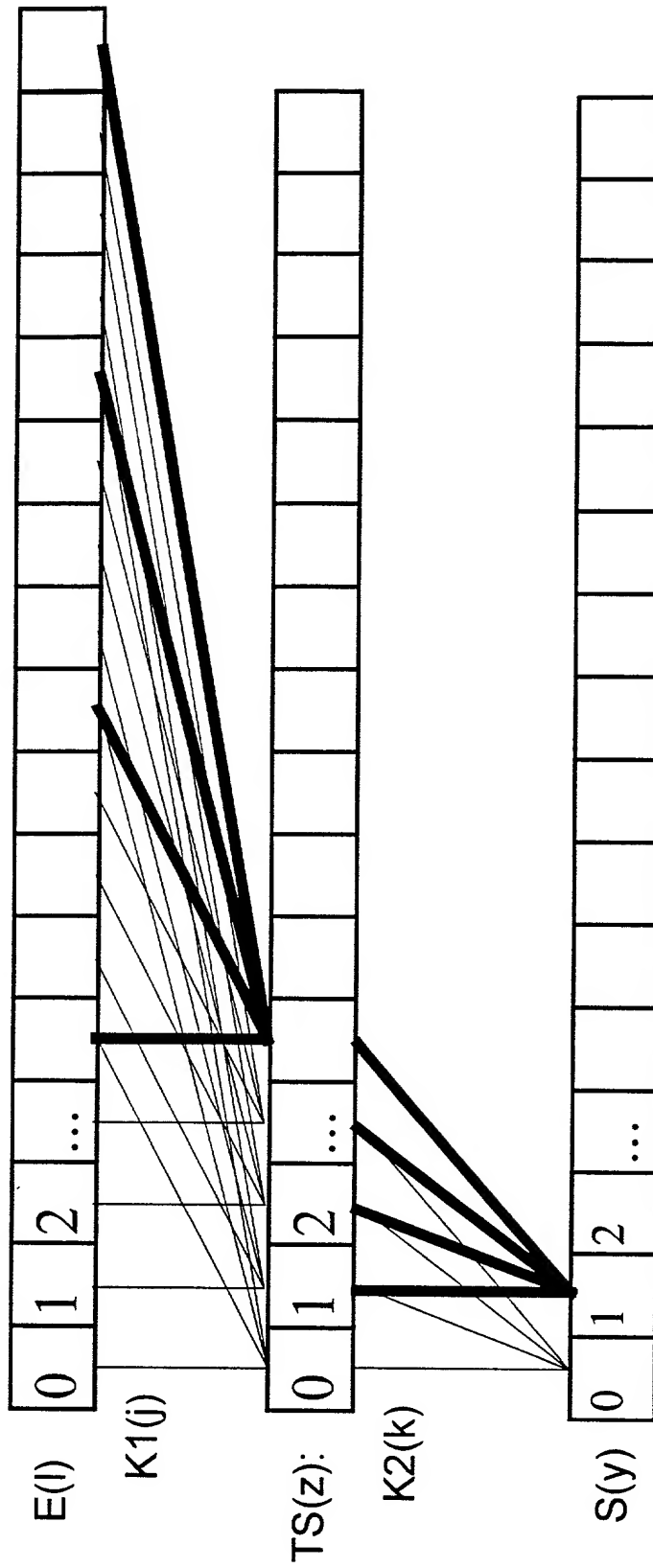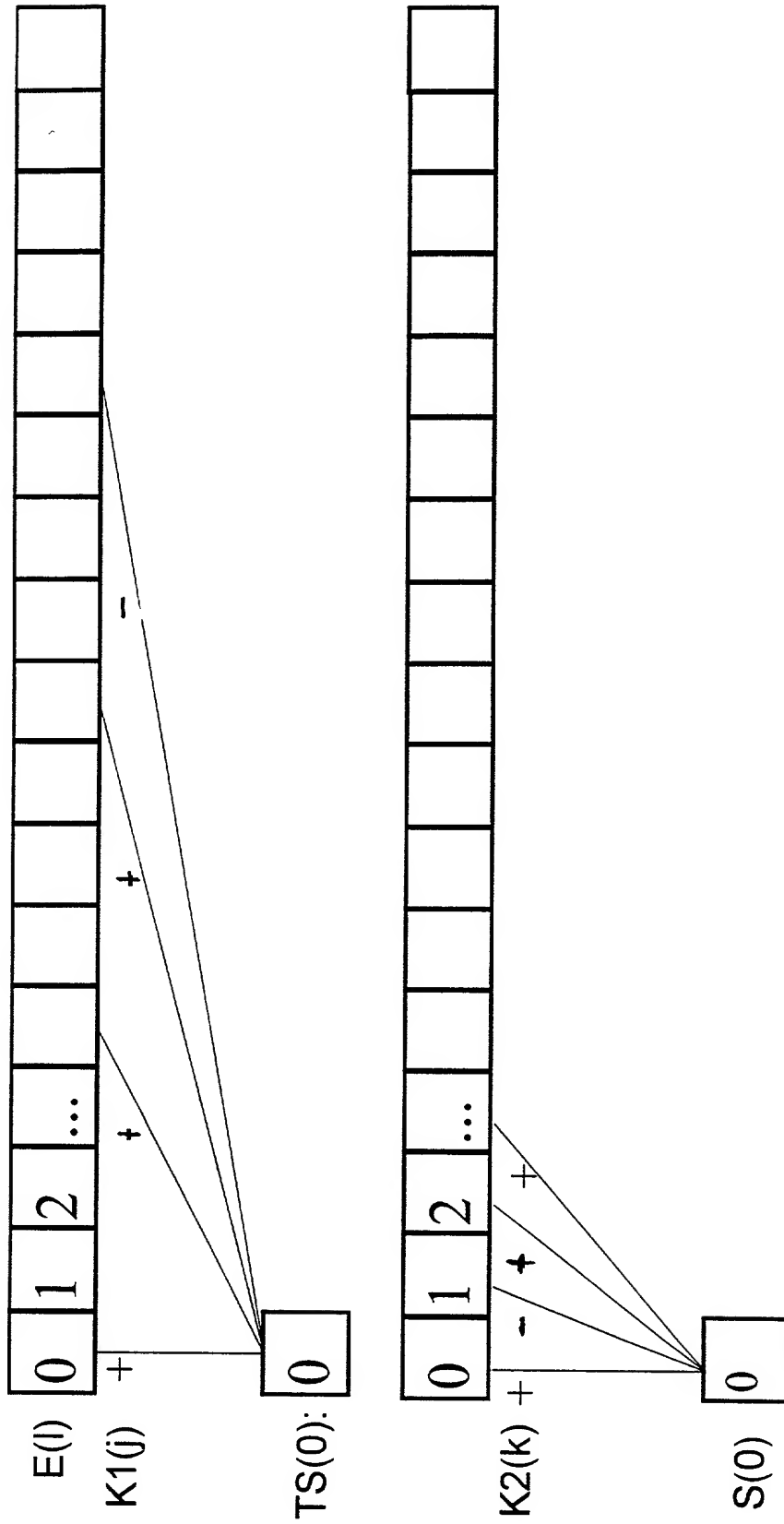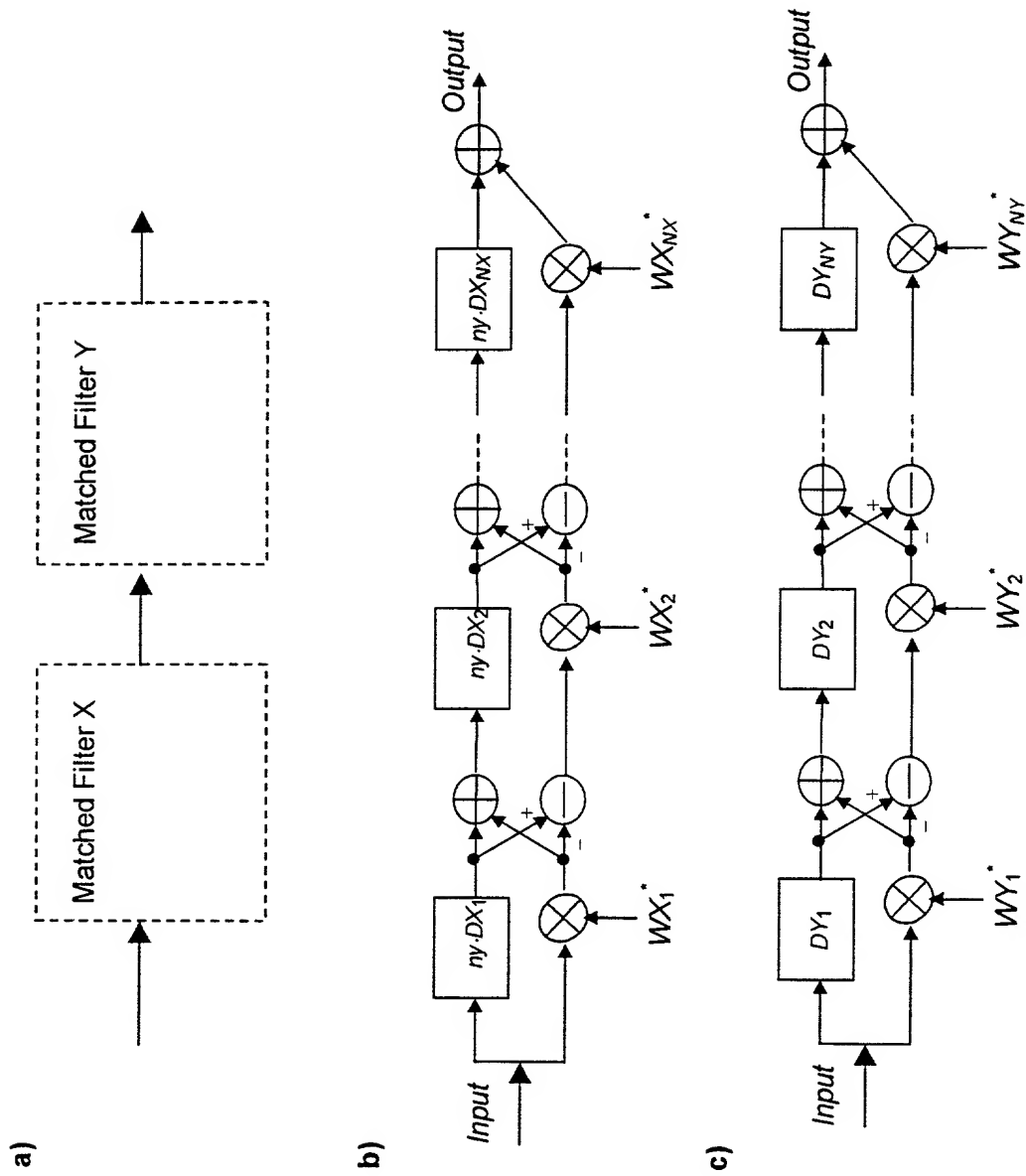
K2(k)

S(y)

0 1 2 ...
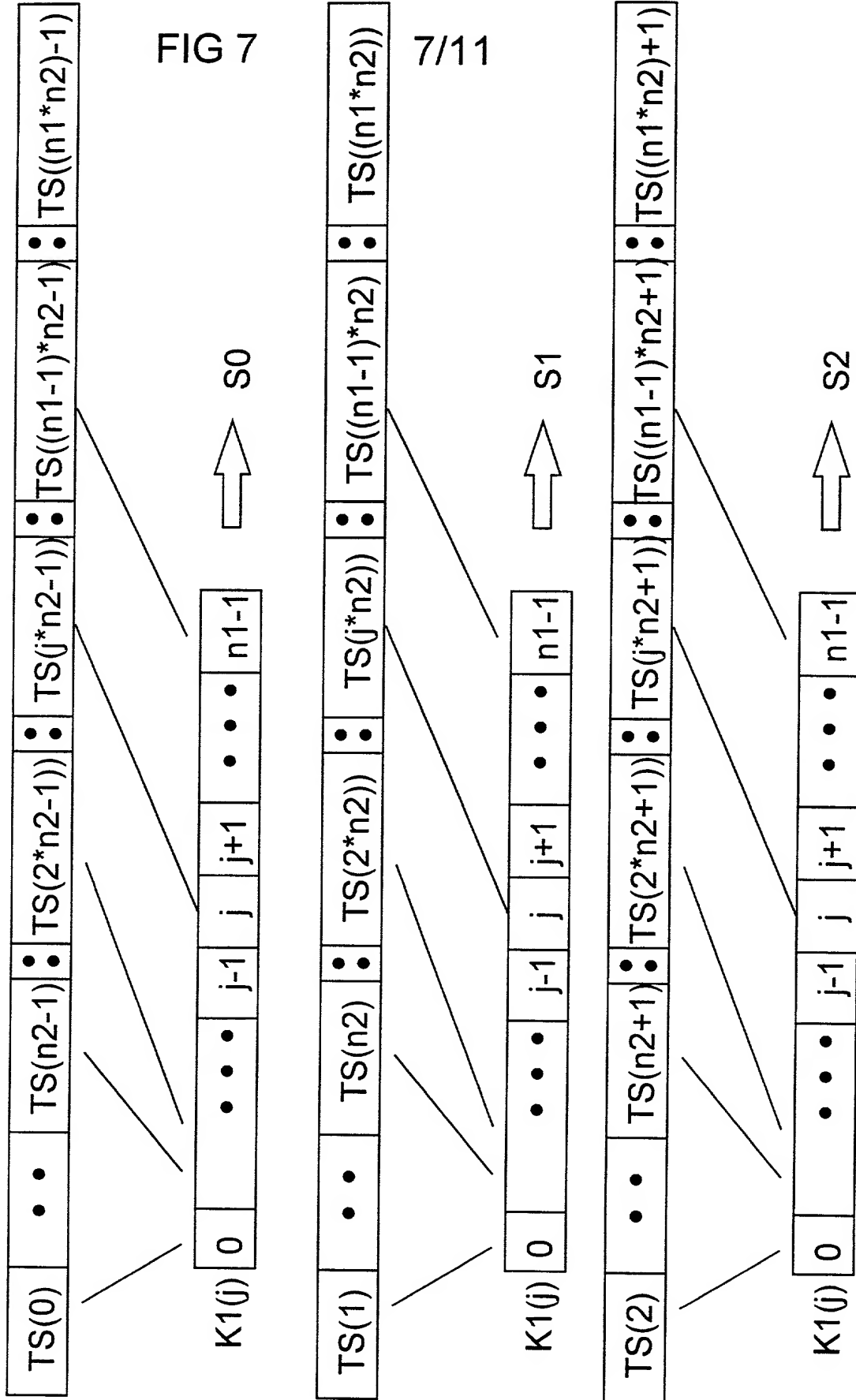
FIG 10   10/11

FIG 11   11/11

Declaration and Power of Attorney For Patent Application
Erklärung Für Patentanmeldungen Mit Vollmacht
German Language Declaration

Als nachstehend benannter Erfinder erkläre ich hiermit an Eides Statt:	As a below named inventor, I hereby declare that:
dass mein Wohnsitz, meine Postanschrift, und meine Staatsangehörigkeit den im Nachstehenden nach meinem Namen aufgeführten Angaben entsprechen,	My residence, post office address and citizenship are as stated below next to my name,
dass ich, nach bestem Wissen der ursprüngliche, erste und alleinige Erfinder (falls nachstehend nur ein Name angegeben ist) oder ein ursprünglicher, erster und Miterfinder (falls nachstehend mehrere Namen aufgeführt sind) des Gegenstandes bin, für den dieser Antrag gestellt wird und für den ein Patent beantragt wird für die Erfindung mit dem Titel:	I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

<u>Verfahren zur Bildung bzw. Ermittlung einer Signalfolge, Verfahren zur Synchronisation, Sendeeinheit und Empfangseinheit</u>	<u>Method for forming and determining a signal sequence, method of synchronization, transmitter unit and receiver unit</u>
deren Beschreibung	the specification of which
(zutreffendes ankreuzen) ☐ hier beigefügt ist. ☒ am __15.02.2000__ als PCT internationale Anmeldung PCT Anmeldungsnummer _____ PCT/EP00/01231 eingereicht wurde und am _____ abgeändert wurde (falls tatsächlich abgeändert).	(check one) ☐ is attached hereto. ☒ was filed on __15.02.2000__ as PCT international application PCT Application No. ____ PCT/EP00/01231 and was amended on _____ (if applicable)
Ich bestätige hiermit, dass ich den Inhalt der obigen Patentanmeldung einschliesslich der Ansprüche durchgesehen und verstanden habe, die eventuell durch einen Zusatzantrag wie oben erwähnt abgeändert wurde.	I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims as amended by any amendment referred to above.
Ich erkenne meine Pflicht zur Offenbarung irgendwelcher Informationen, die für die Prüfung der vorliegenden Anmeldung in Einklang mit Absatz 37, Bundesgesetzbuch, Paragraph 1.56(a) von Wichtigkeit sind, an.	I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).
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IDNR: 2590 / V: 99-1.00 / B:Val

German Language Declaration

Prior foreign appplications
Priorität beansprucht

Priority Claimed

19919545.5	DE	29.04.1999	☒	☐
(Number)	(Country)	(Day Month Year Filed)	Yes	No
(Nummer)	(Land)	(Tag Monat Jahr eingereicht)	Ja	Nein

99109791.6	EP EP	18.05.1999	☒	☐
(Number)	(Country)	(Day Month Year Filed)	Yes	No
(Nummer)	(Land)	(Tag Monat Jahr eingereicht)	Ja	Nein

			☐	☐
(Number)	(Country)	(Day Month Year Filed)	Yes	No
(Nummer)	(Land)	(Tag Monat Jahr eingereicht)	Ja	Nein

Ich beanspruche hiermit gemäss Absatz 35 der Zivil-prozessordnung der Vereinigten Staaten, Paragraph 120, den Vorzug aller unten aufgeführten Anmel-dungen und falls der Gegenstand aus jedem Anspruch dieser Anmeldung nicht in einer früheren amerikanischen Patentanmeldung laut dem ersten Paragraphen des Absatzes 35 der Zivilprozeßordnung der Vereinigten Staaten, Paragraph 122 offenbart ist, erkenne ich gemäss Absatz 37, Bundesgesetzbuch, Paragraph 1.56(a) meine Pflicht zur Offenbarung von Informationen an, die zwischen dem Anmeldedatum der früheren Anmeldung und dem nationalen oder PCT internationalen Anmeldedatum dieser Anmeldung bekannt geworden sind.

I hereby claim the benefit under Title 35. United States Code. §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §122, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occured between the filing date of the prior application and the national or PCT international filing date of this application.

PCT/EP00/01231	15.02.2000	anhängig	pending
(Application Serial No.)	(Filing Date D, M, Y)	(Status)	(Status)
(Anmeldeseriennummer)	(Anmeldedatum T, M, J)	(patentiert, anhängig, aufgegeben)	(patented, pending, abandoned)

(Application Serial No.)	(Filing Date D,M,Y)	(Status)	(Status)
(Anmeldeseriennummer)	(Anmeldedatum T, M; J)	(patentiert, anhängig, aufgeben)	(patented, pending, abandoned)

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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German Language Declaration

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POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. *(list name and registration number)*

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29177
PATENT & TRADEMARK OFFICE

And I hereby appoint

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Voller Name des einzigen oder ursprünglichen Erfinders:	Full name of sole or first inventor:
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Unterschrift des Erfinders Datum 8/10.01	Inventor's signature Date
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Staatsangehörigkeit DE	Citizenship DE
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Voller Name des zweiten Miterfinders (falls zutreffend): *2-00*	Full name of second joint inventor, if any:
BERNHARD RAAF	BERNHARD RAAF
Unterschrift des Erfinders Datum 8-10-07	Second Inventor's signature Date
Wohnsitz MUENCHEN, DEUTSCHLAND	Residence MUENCHEN, GERMANY
Staatsangehörigkeit DE	Citizenship DE
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81475 MUENCHEN	81475 MUENCHEN

(Bitte entsprechende Informationen und Unterschriften im Falle von dritten und weiteren Miterfindern angeben).

(Supply similar information and signature for third and subsequent joint inventors).

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